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Western Regional Air Partnership
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DRAFT REPORT: 2028 FUTURE YEAR OIL AND GAS EMISSION INVENTORY FOR WESTAR- WRAP STATES



Bright ideas. Sustainable change.

Draft Report: 2028 Future Year On-the-Books and On-The-way Oil and Gas Emission Inventory for WESTAR-WRAP States Inventory for the WESTAR-WRAP Region Report Title

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EXECUTIVE SUMMARY

This study provides estimates of criteria air pollutant and greenhouse gas emissions for oil and gas (O&G) exploration and production operations in the Western States Air Resources Council-Western Regional Air Partnership (WESTAR-WRAP) region for a 2028 future year based on the baseline emission inventory documented in the "Revised Final Report: Circa-2014 Baseline Oil and Gas Emission Inventory for the WESTAR-WRAP Region"¹. This analysis was sponsored by the Western Regional Air Partnership (WRAP) Oil and Gas Working Group (OGWG).

The WESTAR-WRAP region consists of 15 states in the Western US, a number of which have substantial O&G exploration and production activities. Future year O&G emission inventories are critical for air quality planning, including regional haze planning. O&G activity in the WESTAR-WRAP Region comprises 40% of US-wide crude oil production (2017²) and 26% of US-wide natural gas production (2018³). Over 70% of active wells in the WESTAR-WRAP region in 2014 were vertical wells and over 75% of spuds were horizontal or directional wells, indicating a shift from development of vertical to horizontal and directional wells that could have substantial effects on future O&G activity and emission estimates.

Ramboll developed Scenario 1 O&G activity forecasts (Continuation of Historical Trends scenario) for basins comprising a vast majority of O&G activity in the WESTAR-WRAP region. O&G activity forecasts were developed by well type (oil, gas, and coalbed methane [CBM]) and spud type (vertical, directional, horizontal) for the following activity parameters: spuds, active well count, oil production, and gas production. California and Colorado forecasts are not included herein because Colorado statewide future year emission inventories are being developed by the Colorado Department of Public Health and Environment (CDPHE) and California forecasts are being developed by the California Air Resources Board (ARB). Forecasts were based on historical O&G activity trends in each basin for each parameter by well type and spud type and are based on several key assumptions:

- Oil development and production continues to be prioritized over gas development and production.
- Development is primarily focused on horizontal wells in tight oil formations such as the Denver Basin (Niobrara Play), Permian Basin, and Williston Basin (Bakken Play). Limited exploration activity for vertical wells.
- Production from legacy vertical wells continues to decline and these wells are gradually taken offline.

There is substantial uncertainty associated with any forecast of O&G activity due to political, economic, and other factors. This study qualitatively discusses this uncertainty but does not quantify uncertainty in the activity forecasts.

Emissions control resulting from regulatory programs such as Federal New Source Performance Standard (NSPS) Subpart OOOO and OOOOa, Federal NSPS Subpart JJJJ, Federal off-road diesel engine tier standards and state specific regulatory programs were incorporated into future year emission estimates, to the extent feasible and to the extent that these programs are expected to have substantial impacts on future year emissions. Emission control estimates are based on the suite of regulations that were "on-the-books" at the time that this future year emission inventory was

¹ Grant et al. (2019), available on the WRAP OGWG website: <https://www.wrapair2.org/OGWG.aspx>

² https://www.eia.gov/dnav/pet/pet_crd_crdpn_adc_mbbbl_a.htm

³ https://www.eia.gov/dnav/ng/ng_prod_sun_a_FPGG_FGW_mmsf_a.htm

developed. Emission control assumptions for fugitive components (LDAR), green completions at oil wells, and pneumatic pumps are based on NSPS OOOOa provisions. EPA is conducting ongoing activities that may lead to future changes to NSPS OOOOa.

On-the-books and on-the-way regulatory control program effects on emissions were estimated for the Denver Basin (Wyoming only), Permian Basin, Williston Basin, Uinta Basin, Green River Basin, and Powder River Basin. Control factors were developed for the Williston, Permian, and Denver Basin (Wyoming only) because substantial activity growth, subject to control by on-the-books regulations, under Scenario 1, is estimated to occur between the baseline inventory and the future year inventory. For the Uinta Basin, a controls analysis was performed because on-the-books Utah State regulations are expected to result in substantial reductions to emissions from existing Uinta Basin oil and gas wellsite sources. Control factors were developed for the Green River and Powder River basins to take advantage of detailed 2014 and 2017 emission inventory files provided by the Wyoming Department of Environmental Quality (WYDEQ). A controls analysis was not performed (i.e., emission rates are assumed unchanged between the baseline year and future year) for the following basins because substantial growth is not estimated between the baseline year and future year under Scenario 1: all Alaska basins, Big Horn Basin, Paradox Basin, Powder River Basin, San Juan Basin, Sweetgrass, Arch, and Wind River Basin.

State-level WESTAR-WRAP region O&G emissions are presented in Table ES-1.

Table ES-1. Future year 2028 WESTAR-WRAP region O&G emissions by state.

Pollutant	AK	AZ	ID	MT	ND	NM	NV	OR	SD	UT	WA	WY
Criteria Air Pollutant Emissions (tons/yr) and Greenhouse Gas Emissions (1000 tons/yr)												
NOx	37,663	1,960	889	6,055	44,072	101,531	156	454	1,295	10,551	444	24,333
VOC	23,880	280	34	35,012	244,841	225,636	269	73	7,978	67,878	36	110,919
CO	11,838	439	272	7,818	68,633	126,678	111	263	1,449	9,889	301	14,891
SOx	1,876	33	4	708	23,680	38,600	15	13	50	600	14	5,503
PM10	1,014	51	10	151	2,810	2,796	11	20	125	539	14	1,123
PM2.5	956	51	10	151	2,562	2,796	11	20	125	539	14	1,137
CO2	-	1,183	245	1,818	28,494	22,437	99	210	1,428	4,594	201	9,562
CH4	-	1	0	124	315	773	0	0	11	352	0	204
N2O	-	0	0	0	0	0	0	0	0	0	0	0
CO2(e)	-	1,209	248	4,905	36,263	41,884	108	216	1,701	13,405	203	14,725
Percent Change from circa-2014 Baseline Emissions												
NOx	-13%	0%	0%	-16%	-35%	25%	0%	0%	41%	-36%	0%	-47%
VOC	-13%	0%	0%	-5%	-19%	22%	0%	0%	-16%	-40%	0%	-58%
CO	-13%	0%	0%	-9%	-18%	12%	0%	0%	-5%	-30%	0%	-30%
SOx	-13%	0%	0%	44%	56%	67%	0%	0%	-18%	3%	0%	-20%
PM10	-13%	0%	0%	-4%	25%	14%	0%	0%	63%	-24%	0%	-12%
PM2.5	-13%	0%	0%	-4%	20%	14%	0%	0%	63%	-24%	0%	-11%
CO2	0%	0%	0%	2%	-1%	11%	0%	0%	54%	-20%	0%	-14%
CH4	0%	0%	0%	-10%	-7%	10%	0%	0%	-6%	-34%	0%	-44%
N2O	0%	0%	0%	-8%	-26%	11%	0%	0%	69%	-23%	0%	-23%
CO2(e)	0%	0%	0%	-6%	-3%	10%	0%	0%	40%	-30%	0%	-27%

¹ not available

The contents of the report by Chapter are summarized as follows:

- Chapter 1.0 provides introductory information on study methodology, scope, and O&G activity in the WESTAR-WRAP region;
- Chapter 2.0 describes the steps taken to develop O&G activity forecasts;
- Chapter 3.0 describes the steps taken to develop the emission controls analysis per on-the-books and on-the-way regulations;
- Chapter 4.0 presents summaries of future year 2028 emissions.

1.0 INTRODUCTION

The WRAP OGWG is sponsoring the development of O&G emission inventories as part of efforts to support regional haze planning in the Western States Air Resources Council-Western Regional Air Partnership (WESTAR-WRAP) region. The O&G emission inventories developed under WRAP OGWG sponsorship will also facilitate other types of air quality planning (e.g., photochemical ozone modeling). More information about WRAP OGWG emission inventory development efforts may be found at the project webpage: <https://www.wrapair2.org/ogwg.aspx>.

This report describes the development of a criteria air pollutant and greenhouse gas (GHG) emissions inventory for O&G field operations in the WESTAR-WRAP region for a 2028 future year, including point (midstream) and nonpoint (wellsite) sources. The future year emissions inventory was compiled by forecasting the baseline emission inventory based on estimated changes to O&G activity and emission controls.

1.1 Scope

1.1.1 Sources

The emission inventory documented herein includes emissions from upstream and midstream O&G sources, consistent with the OGWG Road Map Scope of Work⁴ and the OGWG Roadmap Phase I Report (Grant et al., 2018). Downstream O&G emissions are not included. Consistent with the baseline O&G emission inventory (Grant et al., 2019), the future year emission inventory includes wellsite, gathering, and processing subsectors (items 1, 5, and 6 in Figure 1-1). Item 1) On-shore Petroleum and Natural Gas Production is referred to as "wellsite" sources; emissions from wellsite sources are typically classified as nonpoint sources⁵. Items 5) Gathering and Boosting and 6) Gas Processing Plant are collectively referred to as "midstream" sources; emissions from midstream sources are typically classified as point sources. The classification of well-site emissions as nonpoint and midstream emissions as point sources is consistent with O&G emission inventory classifications used in the WRAP Phase III study⁶, West-wide Jumpstart Air Quality Modeling Study (WestJUMP AQMS)⁷, 2011 Western Air Quality Study⁸, and 2014 NEI methodology⁹.

⁴ https://www.wrapair2.org/pdf/11162017_WRAPOGWGWorkgroup_RoadMapSOW.pdf

⁵ There are exceptions; for example, several wellsite sources in the Uinta Basin are available by facility and will be included in emission inventories as point source emissions.

⁶ <https://www.wrapair2.org/PhaseIII.aspx>

⁷ <https://www.wrapair2.org/WestJumpAQMS.aspx>

⁸ <http://vibe.cira.colostate.edu/wiki/wiki/1018/3sens-2011a-modeling-platform>

⁹ <https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-technical-support-document-1a2>

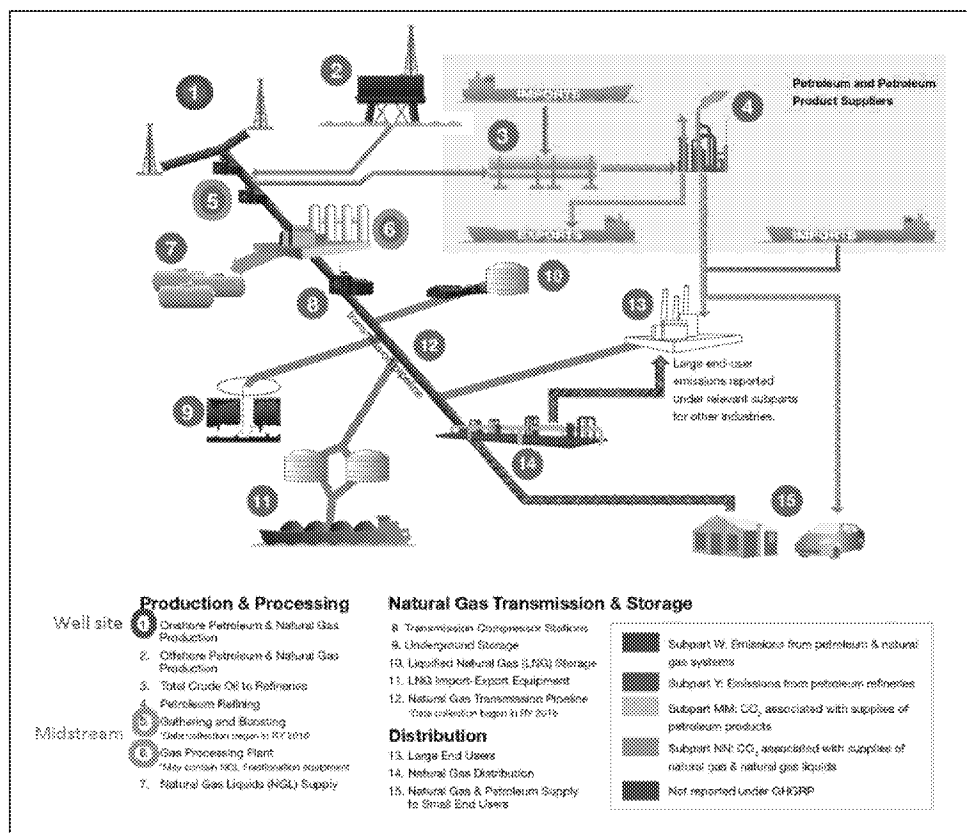


Figure 1-1. Example Petroleum and Natural Gas Industry schematic^{10, 11}.

1.1.2 Geographical Scope

The WESTAR-WRAP region includes 15 states, a number of which have substantial O&G production and generate substantial O&G emissions. Figure 1-2 shows major basins in the WESTAR-WRAP region. California O&G emissions are estimated by the California Air Resources Board (ARB) and Colorado emissions are estimated by the Colorado Department of Public Health (CDPHE) and are not included herein. Several states have limited or zero O&G production and O&G sector emissions: Arizona, Hawaii, Idaho, Nevada, Oregon, South Dakota, and Washington. Emissions were estimated by county, distinguishing between tribal and non-tribal sources.

¹⁰ Source: <https://www.epa.gov/ghcreporting/ghgrp-and-oil-and-gas-industry>

¹¹ This figure shows O&G subsectors for which emissions have been developed in this study. It is important to consider that Petroleum and Natural Gas Industry equipment is typically tailored to meet field, basin, and/or region-specific infrastructure requirements.

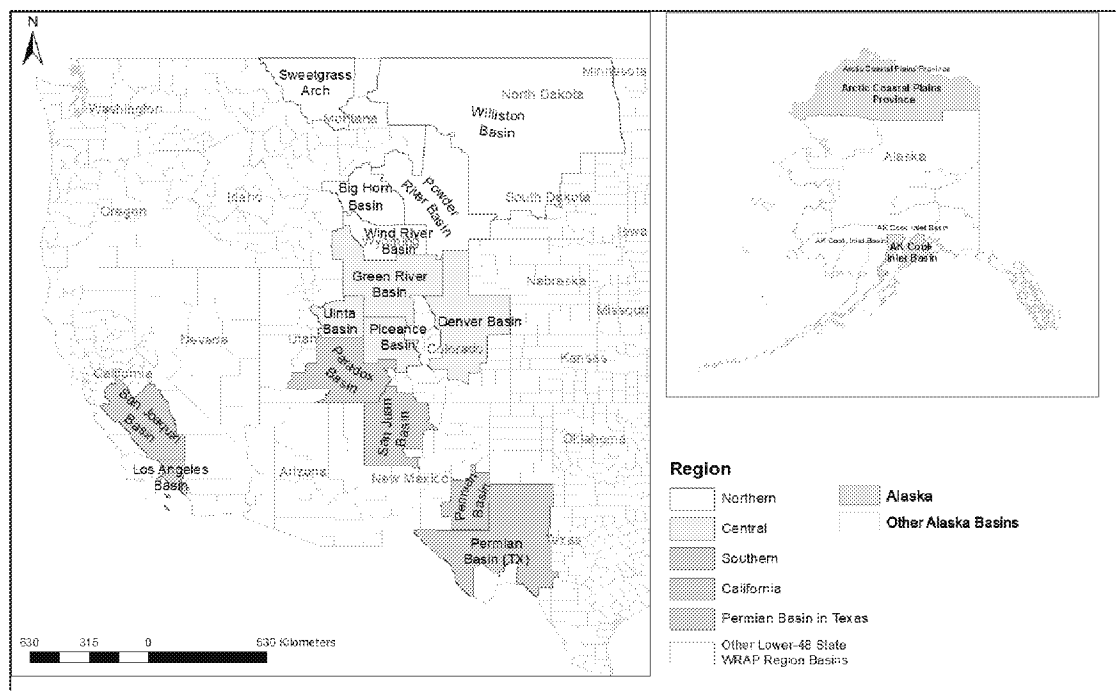


Figure 1-2. WESTAR-WRAP region, including major O&G basins.

1.1.3 Temporal Scope

The future year emission inventory was developed for future year 2028. The baseline 2014 emission inventory (Grant et al., 2019) is the basis of the future year emission inventory compilation. O&G activity forecasts were developed to forecast O&G activity changes from 2014 to 2023, under the assumption that – given high uncertainty in O&G activity forecasts – farther future year O&G activity forecasts to 2028 are not expected to be more predictive of 2028 O&G activity compared to 2023 O&G activity forecasts. O&G activity was held constant from 2023-2028 because of high uncertainty in forecasting farther than 9 years. O&G activity forecasts are described in Section 2.0.

1.1.4 Pollutants

Emissions were estimated for the following pollutants;

- Nitrogen oxide (NO_x)
- Volatile organic compounds (VOC)
- Carbon monoxide (CO)
- Particular matter less than 10 microns (PM₁₀)
- Particulate matter less than 2.5 microns (PM_{2.5})
- Sulfur oxides (SO_x)
- Carbon dioxide (CO₂)
- Methane (CH₄)
- Nitrous oxide (N₂O)

1.2 Well Count and Production Data

O&G related activity data were obtained from the IHS Enerdeq database¹² queried via online interface. The IHS Enerdeq database uses data from each state's Oil and Gas Conservation Commission (OGCC or equivalent) as sources of information for oil and gas activity. This data is also available directly through database querying tools maintained by the respective agencies. It was determined that the IHS database is more accurate and complete than the state databases. The IHS database was also used to develop emission inventories in the WRAP Phase III, WestJump AQMS, and IWDW studies. Therefore, the IHS database was chosen as the basis for O&G activity statistics for this analysis. Two types of data were queried from the Enerdeq database: production data and well data. Production data includes information relevant to producing wells and well data includes information relevant to drilling activity ("spuds") and completions.

Production data were obtained for all counties in the WESTAR-WRAP region as IHS "298" format data files. The "298" well data contain information regarding historical O&G production. The "298" well data were processed with a PERL script to develop a database by American Petroleum Institute (API)-number, well type (oil, gas, or coalbed methane; CBM), spud type (directional, horizontal, or vertical), annual gas production, oil production, and water production with latitude and longitude information.

The API number in the IHS database consists of 14 digits as follows:

- Digits 1 to 2: state identifier
- Digits 3 to 5: county identifier
- Digits 6 to 10: borehole identifier
- Digits 11 to 12: sidetracks
- Digits 13 to 14: event sequence code (recompletions)

Based on the expectation that the first 10 digits, which include geographic and borehole identifiers, would predict unique sets of well head equipment, the unique wells were identified by the first 10 digits of the API number.

Well data were also obtained from the IHS Enerdeq database for all WRAP region states as IHS "297" well data. The "297" well data contain information on spuds and completions. The "297" well data were processed with a PERL script to arrive at a database of by-API-number and spud type, spud and completion dates with latitude and longitude information. Drilling events in 2014 were identified by indication that the spud occurred within 2014. If the well API number indicated the well was a recompletion, it was not counted as a drilling event, but if the API number indicated the well was a sidetrack, it was counted as a drilling event.

O&G activity for the WRAP Region states is summarized in Grant et al. (2019); details by basin, spud type and well types are available in the 2014 O&G activity spreadsheet¹³. O&G activity forecasts for the future year emission inventory are described in Section 2.0.

¹² All data queried from IHS Enerdeq is subject to copyright protections

¹³ https://www.wrapair2.org/pdf/WESTAR_OG_Activity_10Aug2016_distributed.xlsm

2.0 O&G ACTIVITY FORECASTS

Ramboll developed basin specific O&G activity forecasts for the following O&G activity parameters by well type (oil, gas, and coalbed methane [CBM]) and spud type (vertical, directional, horizontal):

- Spuds
- Active well count
- Oil production
- Gas production

2.1 Scenario 1: Continuation of Historical Trends

Figure 1-2 shows the basins for which unique Scenario 1 forecasts were developed. These basins represent 98.6% of gas production, 99.6% of oil production, 99.5% of spuds, and 97.6% of active well count in the WRAP region in 2014. Note that, as mentioned previously, O&G activity forecasts were not developed for California and Colorado herein because state agencies are developing these forecasts. Outside of the basins identified in Figure 1-2; O&G activity was assumed unchanged from 2014. Future O&G production is difficult to forecast and forecasts to farther future years are more uncertain as a result of economic and political factors; therefore, O&G activity forecasts to 2023 are assumed for future year 2028. The basins were grouped into regions for organizational purposes. Four meetings¹⁴ were held to present the draft forecasts to state agencies, one for each region identified in Figure 1-2. During the meetings, Ramboll presented the results for each basin in a given region and members provided feedback on the forecast estimates.

Forecasts were based on historical O&G activity trends in each basin for each parameter by well type and spud type. The guiding assumptions for the forecast estimates were:

- Oil development and production continues to be prioritized over gas development and production.
- Development is primarily focused on horizontal wells in tight oil formations such as the Denver Basin (Niobrara Play), Permian Basin, and Williston Basin (Bakken Play). Limited exploration activity for vertical wells.
- Production from legacy vertical wells continues to decline and these wells are gradually taken offline.

Alaska-wide O&G activity change was not based on historical trends analysis. Alaska forecasts were based on the February 2019 presentation, "Fall 2018 Production Forecast: House Finance Committee"¹⁵. In this presentation, 2023 oil production is estimated at approximately 475 Mbbl/day (slide 5). 2014 oil production is estimated at 546.6 Mbbl/day in the Alaska Department of Revenue-Tax Division 12/19/2017 "Production History and Forecast by Production Area from Fall 2017 RSB"¹⁶. The 2014 to 2023 oil production scalar (i.e., 13% Alaska-wide production decrease) was applied to forecast all emission source categories in Alaska.

¹⁴ March 18, 2019 Northern Basins teleconference; March 19, 2019 Central Basins teleconference; March 20, 2019 Southern Basins teleconference; and March 21, 2019 Alaska Basins teleconference.

¹⁵ http://www.akleg.gov/basis/get_documents.asp?session=315&docid=11246, accessed August 2019

¹⁶ <http://www.tax.alaska.gov/sourcesbook/AlaskaProduction.pdf>, accessed August 2019

California and Colorado forecasts are not included herein because Colorado statewide future year emission inventories are being developed by the Colorado Department of Public Health and Environment (CDPHE) and California forecasts are being developed by the California Air Resources Board (ARB).

Uncertainty: Forecasts are highly sensitive to factors that are difficult to predict (e.g., political, economic). Forecasts are also influenced by NEPA process (Projects and Regional Management Plans) and other regulatory factors (e.g., attainment status).

2.1.1 Scenario 1: O&G Activity Scaling Factor Development

The 2028 to 2014 ratio of each O&G activity metric by well type (summed over spud types) comprise the emission forecast scaling factors as shown in Equation 1.

$$f_i = \frac{W_{i,2028}}{W_{i,2014}} \quad (\text{Equation 1})$$

where:

f_i is the scaling factor for parameter i (oil production, gas production, active well count, and spud count)

$W_{i,2014}$ is the historical value of parameter i in 2014

$W_{i,2028}$ is the forecast value of parameter i in 2028

The O&G activity scaling factor associated with each emission source category is shown in Table 2-1. The baseline inventory emissions were available for most wellsite categories by well type, but not by spud type. Therefore, factors by well type aggregated across spud type were used to scale the baseline inventory to the future year (see Table 2-1). Appendix A includes additional details on forecasts by spud type and well type that are the basis of the scaling factors presented in Table 2-2.

Table 2-1. Scaling parameter by O&G source category.

Forecast O&G Activity Surrogate	Emission Source Category
Active Well Count	Refracing
	Water Pump Engines
	Well Venting
	Wellhead Engines (e.g., compressors, artificial lift)
	Workover rigs
	Blowdowns
	Heaters
	Fugitive Leaks
	Pneumatic Devices
	Pneumatic Pumps
	Well Venting
	Recompletions

Forecast O&G Activity Surrogate	Emission Source Category
Gas Production (i.e., total, primary, associated, CBM)	Midstream Sources
	Produced Water Tanks
	Dehydrators
	Casinghead Gas
Liquid Hydrocarbon Production (i.e., oil, condensate)	Oil Tanks
	Condensate Tanks
	Tank Truck/Railcar Loading
Spud Count	Completions
	Drill Rigs
	Hydraulic Fracturing Engines
	Mud Degassing

Table 2-2. Summary of 2028 to 2014 scaling ratio by O&G activity metric and Basin.

Activity Metric	Well Type			
	All	CBM	Gas	Oil
Alaska (All Basins)				
Oil Production	0.87			
Big Horn Basin				
Gas Production	0.82	--	0.49	0.99
Oil Production	0.71	--	0.78	0.71
Spud Count	0.66	--	--	--
Well Count	0.72	--	0.80	0.71
Denver Basin (WY Only)				
Gas Production	5.15	--	--	5.15
Oil Production	3.98	--	--	3.98
Spud Count	0.66	--	--	--
Well Count	2.26	--	--	2.26
Green River Basin				
Gas Production	0.96	0.64	0.96	0.99
Oil Production	1.00	--	1.01	0.98
Spud Count	0.69	--	--	--
Well Count	1.12	0.64	1.15	0.88
Paradox Basin				
Gas Production	1.07	1.48	0.92	0.97
Oil Production	0.61	--	0.24	0.61
Spud Count	0.18	--	--	--
Well Count	0.81	0.99	0.97	0.65
Permian Basin				
Gas Production	2.34	--	2.94	2.15
Oil Production	2.33	--	17.19 ^a	1.96

Activity Metric	Well Type			
	All	CBM	Gas	Oil
Spud Count	0.55	--	--	--
Well Count	0.95	--	0.91	0.97
Powder River Basin				
Gas Production	0.62	0.25	0.53	1.87
Oil Production	0.87	--	0.78	0.88
Spud Count	0.26	--	--	--
Well Count	0.60	0.40	0.74	0.90
San Juan Basin				
Gas Production	0.59	0.53	0.63	1.38
Oil Production	1.12	--	0.80	1.23
Spud Count	0.44	--	--	--
Well Count	0.90	0.91	0.91	0.78
Sweetgrass Arch				
Gas Production	0.75	--	0.74	0.93
Oil Production	0.55	--	0.78	0.54
Spud Count	0.44	--	--	--
Well Count	0.94	--	0.87	1.00
Uinta Basin				
Gas Production	0.40	0.51	0.33	0.70
Oil Production	0.67	--	0.50	0.68
Spud Count	0.20	--	--	--
Well Count	0.93	0.99	0.94	0.92
Williston Basin				
Gas Production	2.35	0.89	0.58	2.46
Oil Production	0.94	--	0.49	0.95
Spud Count	0.24	--	--	--
Well Count	1.34	1.00	0.88	1.43
Wind River Basin				
Gas Production	0.86	0.00	0.72	2.01
Oil Production	0.90	--	0.72	0.91
Spud Count	0.63	--	--	--
Well Count	0.97	0.11	1.00	0.97

^a Permian Basin condensate production from horizontal wells increased from 2.3 million barrels per year (MMbbl/yr) in 2015 to 13.8 MMbbl/yr in 2017. The substantial rate of increase from 2015 to 2017 was extended to 2023.

3.0 SCENARIO 1 EMISSION CONTROL ESTIMATES

Emissions control resulting from regulatory programs such as NSPS Subpart OOOO and OOOOa, NSPS JJJJ standards, Federal off-road diesel engine tier standards and state specific regulatory programs were incorporated into future year emission estimates, to the extent feasible and to the extent that these programs are expected to make substantial impacts to future year emissions. Emission control estimates are based on the suite of regulations that were “on-the-books” at the time that this future year emission inventory was developed. Emission control assumptions for fugitive components (LDAR), green completions at oil wells, and pneumatic pumps are based on NSPS Subpart OOOOa provisions. EPA is conducting ongoing activities that may lead to future changes to NSPS Subpart OOOOa.

A controls analysis was performed and the effects of applicable regulations were applied, to the extent feasible, for the basins listed below.

- Denver Basin (Wyoming only)
- Permian Basin
- Williston Basin
- Uinta Basin
- Green River Basin
- Powder River Basin

Control factors were developed for Williston, Permian, and Denver (Wyoming only) basins because substantial activity growth, subject to control by on-the-books regulations, under Scenario 1 is estimated to occur between the baseline inventory and the future year inventory. For Uinta Basin, a controls analysis was performed because on-the-books Utah State regulations are expected to result in substantial reductions to emissions from existing oil and gas wells. Control factors were developed for the Green River and Powder River basins to take advantage of detailed 2014 and 2017 emission inventory files provided by the Wyoming Department of Environmental Quality (WYDEQ).

A controls analysis was not performed (i.e., emission rates per unit production or per well or spud were assumed unchanged between the baseline year and future year) because substantial growth is not estimated in the basins listed below between the baseline year and future year under Scenario 1.

- Alaska (All Basins)
- Big Horn Basin
- Paradox Basin
- Powder River Basin
- San Juan Basin
- Sweetgrass Arch
- Wind River Basin

The methodology used to estimate regulation effects on wellsite O&G emissions is described below. Point source O&G emissions may also be subject to additional control per requirements such as NSPS Subpart OOOO, and NSPS Subpart OOOOa; however, information was not readily available from point source emission inventory databases upon which to estimate the effect on emissions of such controls. Point source O&G emission forecasts do not include additional control resulting from regulatory control

programs. Additional controls per the 2018 Final November 2018 BLM Methane Rule¹⁷ were assumed negligible. Table 3-1 below summarizes “on-the-books” federal regulations that affect wellsite emissions source categories. A detailed table summarizing all state and federal regulations is available in Appendix A¹⁸ of Grant et al. (2018).

State specific requirements applicable to the control factors analysis for Utah are provided in Section 3.1. The effects of state specific programs for Wyoming basins is incorporated implicitly in the WYDEQ 2014 and 2017 data submissions which are the basis of the Wyoming basins control analysis. State specific regulatory effects on control factors in the Williston and Permian Basins are not expected to result in substantial effects on emissions beyond Federal standards effects.

Table 3-1. Summary of federal “on-the-books” regulations affecting O&G source categories considered in this inventory.

Source Category	Regulation	Enforcing Agency	Applicability	Effective Date
Drill Rigs, Fracturing Engines	Nonroad engine Tier standards (1-4): Limits emission rates for compression ignition engines.	US EPA	All applicable off-road mobile engine categories	Phase-in from 1996 - 2014
Pneumatic Controllers	NSPS Subpart OOOO: Six standard cubic-feet per hour (scfh) at well sites (i.e. low bleed gas-driven pneumatic controllers).	US EPA	New and modified ¹ sources only (NSPS OOOO and OOOOa)	NSPS OOOO: August 2011
Compressor Engines, Artificial Lift Engines	NSPS Subpart JJJJ: Limits emission rates for spark ignition engines.	US EPA	New and modified spark-ignition engines	Phase-in from 2005 to 2011
Well Completions	NSPS Subpart OOOO and OOOOa: Green completions required at gas and oil well sites except for specific well types (wildcat, delineation, oil wells with a gas-oil ratio of less than 300 standard cubic-feet of gas per barrel, and oil wells for which a gas pipeline is not available).	US EPA	All applicable completions	NSPS OOOO and OOOOa: Phase-in from 2015
Storage Tanks	NSPS Subpart OOOO and OOOOa: Storage vessels with VOC emissions equal to or greater than 6 tpy must reduce emissions by at least 95 percent. This can be accomplished by routing emissions to a combustion device.	US EPA	New and modified ¹ sources only (NSPS OOOO and OOOOa)	NSPS OOOO and OOOOa: August 2011
Fugitives	NSPS Subpart OOOOa: LDAR programs are required at applicable well sites.	US EPA	New and modified sources (NSPS OOOOa)	NSPS OOOOa: Phase in from 2015

¹⁷ 43 CFR 3160, 43 CFR 3160.43 CFR 3170

¹⁸ https://www.wrapair2.org/pdf/Item4_OGWSG_WF_AppendixA.xlsx

Source Category	Regulation	Enforcing Agency	Applicability	Effective Date
Pneumatic Pumps	NSPS Subpart OOOOa: Route emissions from pneumatic diaphragm pumps to existing onsite control device, if available.	US EPA	New and modified sources (NSPS OOOOa)	NSPS OOOOa: Phase in from 2015

¹ The fraction of sources that would be classified as "modified" under NSPS OOOO and/or NSPS OOOOa is unavailable. Controls were applied to new sources only.

3.1 Utah State Oil and Gas Registration Requirements

As mentioned above, application of controls to the Uinta Basin focused on emission source categories with substantial emissions for which state specific programs are expected to result in substantial emission reductions. Facility-level throughput and emissions information available from the Utah Air Agencies Uinta Basin emission inventory was used to estimate facility-level emission reductions for Uintah and Duchesne counties. Table 3-2 describes controls application for the Uinta Basin. Uintah and Duchesne counties accounted for a vast majority of baseline emissions from pneumatic controllers, tanks, and fugitive components in the Uinta Basin; emission reductions for these categories were not estimated for other Uinta Basin counties. Facility-level dehydrator emissions necessary to estimate control effects were not available outside of Uintah and Duchesne counties, therefore, dehydrator emission reductions were not applied for other Uinta Basin counties.

Table 3-2. Uinta Basin future year controls implementation.

Source	State Regulation	Future Years Control Assumption
Oil and Condensate Tanks	R307-506: A tank or a tank battery at existing oil and gas well sites are required to control VOC emissions at 95% if throughput of crude oil at 8,000 barrels or greater or 2,000 barrels of condensate or greater per year on a rolling 12 month basis. Sources can demonstrate less than 4 tpy with site specific sample and calculations based upon AP-42. A tank or tank battery at an oil and gas site that begins operations after January 1, 2018 are required to control VOC emissions at 95% for one year and can remove if throughput less than the 8,000 barrels of crude oil or 2,000 barrels of condensate or demonstrate emissions less than 4 tpy. Emergency tanks are exempt from R307-509 if not used as an active storage tank, emptied 15 days after receiving fluids and equipped with a liquid level gauge.	Facilities with 2014 tank throughput greater than 8,000 barrels of oil or 2,000 barrels of condensate which were uncontrolled in the baseline inventory were reduced by 95% in the future year inventory.
Fugitive Components (LDAR)	Oil and gas well sites that require controls in accordance with R307-506 (tanks) or R307-507 (dehydrators) are required to perform LDAR in accordance with OOOOa	LDAR implementation was assumed to result in 50% reductions to fugitive component emissions at all (existing and new) wells based on average reductions from annual and quarterly inspections assumed in CDPHE (2014).
Pneumatic devices	As of April 2017 all existing pneumatic controllers shall meet OOOO standards.	Assume all devices are low or no bleed devices.

Source	State Regulation	Future Years Control Assumption
Dehydrators	Dehydrators with VOC emissions of 4 tpy or greater, either alone or combined with emissions from tanks, require controls at 95%	Facilities with 2014 dehydrator VOC emissions of 4 tpy or greater were reduced by 95% in the future year inventory.

3.2 Nonroad Diesel Engine Standards and Fuel Sulfur Standards

Williston and Permian basins include substantial emissions contributions from source categories expected to be affected by Federal Nonroad Diesel Engine and Fuel Sulfur Standards (drilling rigs and hydraulic fracturing engines). EPA MOVES 2014b¹⁹ was run with default inputs for base year 2014 and future year 2028. Model outputs were used to develop basin-wide emissions per unit population for “other oil field equipment” (SCC 2270010010) for base year 2014 and future year 2028 for Montana, North Dakota and New Mexico. Emissions per unit population reflect the predicted fleet mix of engines – for various tier standards from baseline uncontrolled engines through Tier IV engines – and are used as a representation of fleet turnover for drilling rigs and fracing engines. The ratios of 2028 to 2014 per unit emissions are the control factors estimates which account for federal non-road tier standards and diesel fuel sulfur standards. Permian Basin emission rates implemented in the baseline inventory for drill rigs and hydraulic fracturing engines include substantial use of Tier 4 engines and were already at or below MOVES 2014b estimates, therefore no emission reduction was estimated for the Permian Basin.

3.3 New Source Performance Standards for Pneumatic Devices

Pneumatic device control factors were developed for the Williston and Permian basins according to NSPS Subpart OOOO and OOOOa. Pneumatic devices at all (existing and new) wells were assumed to be low-bleed (i.e. less than 6 standard cubic-feet per hour bleed rate).

3.4 New Source Performance Standards for Completions

NSPS Subpart OOOO and OOOOa require control of emissions from (i) hydraulically fractured gas well completions by flare from August 23, 2011 to December 31, 2014 and with green completion technology from January 1, 2015 and (ii) hydraulically fractured oil well completions by green completion technology from September 18, 2015. Completions represent approximately 2% of Permian Basin and 4% of Williston Basin baseline VOC emissions. In 2014, oil wells completed in the Williston and Permian Basin were not subject to NSPS Subpart OOOOa requirements and included a mix of venting, flaring, and green completion technology. Given uncertainty in the feasibility of routing completion gas to pipeline in these basins, NSPS Subpart OOOOa requirements were assumed to be fulfilled by a mix of flaring and green completion technology; completion venting activity was assumed negligible and the relative split between the flaring and green completion volume per completion in the baseline inventory was assumed for the future year inventory.

3.5 New Source Performance Standards for Crude Oil and Condensate Tanks

Crude oil and condensate tank control factors were developed according to NSPS Subpart OOOO and OOOOa requirements. NSPS Subpart OOOO requires control of condensate and oil tank VOC emissions for tanks that emit over 6 tons per year VOC if the source was constructed or modified after August 23, 2011; NSPS OOOOa extends the requirements to control of methane emissions. The compliance

¹⁹ <https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves>

deadline was April 15, 2014 for tanks constructed after April 12, 2013 and April 15, 2015 for tanks constructed between August 23, 2011 and April 12, 2013.

Close to 100% of Williston Basin tanks were controlled in the base year, therefore, Williston Basin tank emission rates were assumed unchanged in the future year inventory. Ramboll estimated control scalars for Permian Basin tanks. Permian Basin control factors were based on application of control to tanks with the potential to emit 6 tons per year VOC, but not to tanks with the potential to emit less than 6 tons per year VOC. For Permian Basin tank emissions added after base year 2014, 95% of oil and condensate tank and emissions were assumed to be controlled by flare (56%), vapor recovery unit (2%), or other device types (typically an enclosed combustor; 38%).

Similar to the baseline inventory, capture efficiency was assumed to be 100%.

3.6 New Source Performance Standards for Wellsite Natural-Gas Fired Engines

NSPS Subpart JJJJ requirements are applicable to natural gas-fueled wellsite engines. In the Permian and Williston basins, a vast majority of natural gas-fueled wellsite engines are artificial lift engines. Permian Basin artificial lift engine emission rates were not changed from the base year to the future year because 99% of natural gas-fueled artificial lift engines in the baseline inventory were assumed to meet NSPS JJJJ standards based on operator survey data (Grant et al., 2019). Williston Basin artificial lift engines fleetwide emission factors were estimated for the future year assuming that engines are added between the baseline and future year, with similar wellsite prevalence and configuration as in the baseline inventory, and that these engines meet NSPS Subpart JJJJ standards and have an average useful life of 40 years.

3.7 Associated Gas Venting and Flaring

The baseline inventory includes substantial casinghead gas flaring emissions for the Williston Basin. For the future year emission inventory, the percentage of associated gas that is not sent to pipeline in the Williston Basin was estimated to be 91% (9% not sent to pipeline) based on the NDIC Order 24665 (Policy/Guidance, Version 112018) post-November 1, 2020 gas capture goal.

3.8 New Source Performance Standards for Fugitive Devices

NSPS Subpart OOOOa requires routine fugitive leak monitoring for well sites and compressor stations constructed or modified after September 18, 2015. LDAR program requirements specify that LDAR surveys are conducted twice annually after the initial survey. LDAR implementation for the Williston and Permian basins is assumed to result in 50% reductions to fugitive component emissions at new wells based on average reductions from annual and quarterly inspections reductions assumed in CDPHE (2014).

3.9 New Source Performance Standards for Pneumatic Pumps

Emission control factors for pneumatic pumps resulting from NSPS Subpart OOOOa were not estimated. NSPS Subpart OOOOa requirements apply only to diaphragm pumps but not lean glycol circulation pumps or piston-driven chemical injection pumps. The base year inventory was based on generic pneumatic pump configurations which did not distinguish pump type. Not including additional control of pneumatic pumps per on-the-books regulations is a conservative assumption, consistent with Grant et al. (2018).

3.10 Wyoming Basins Control Factor Estimates

Controls were estimated for Denver, Green River, and Powder River basins in Wyoming based on detailed 2014 and 2017 emission inventory data provided by WYDEQ. Denver Basin controls were

estimated to account for differences in emissions for wells that are expected to be added in the Denver Basin in the Niobrara formation which have a different equipment setup and emissions regime than the legacy wells in that basin. Green River and Powder River basin O&G activity is estimated to decline under Scenario 1 for most parameters. An analysis of emission rate differences between the baseline and future year inventories based on detailed emission inventory data provided by WYDEQ was used to estimate control factors for source categories with substantial NOx and VOC emissions.

3.10.1 Denver Basin

Baseline emissions per O&G activity surrogate were estimated for each nonpoint source category; these emissions are representative of the active wells in the baseline inventory which are dominated by legacy vertical wells. Wells that are being added in the Denver Basin between the baseline and future year are expected to be primarily horizontal wells drilled in the Niobrara formation. The new horizontal wells are expected to have equipment configurations and emissions that differ substantially from the legacy vertical wells. WYDEQ 2017 annual emission inventory estimates for a substantial number of new Denver Basin horizontal wells were used to develop horizontal well emission rates. The control factors developed for the Denver Basin represent the change in emissions from legacy vertical wells in the base year inventory to new horizontal wells.

3.10.2 Green River and Powder River Basins

Control factors were developed for specific Green River and Powder River basin source categories with substantial emission contributions and emission rate changes based on analysis of WYDEQ provided 2014 and 2017 annual emission inventory estimates for several operators. Emission rates were assumed unchanged from the base year for source categories that either (1) did not have substantial emission contributions or (2) for which emission changes were small. Circa-2014 baseline and 2017 emission rates were used to develop control factors for condensate tanks and wellhead engines in the Green River Basin and wellhead engines in the Powder River Basin.

3.11 Controls Summary

Scenario 1 future year 2028 changes in emissions by basins and source category resulting from control factors application is presented in Table 3-3.

Table 3-3. Scenario 1 control factors summary.

Description	Applicability ¹	Percent Change in Emissions from Baseline Inventory								
		NOx	VOC	CO	SOx	PM ₁₀	PM _{2.5}	CO ₂	CH ₄	N ₂ O
Williston, MT										
Artificial Lift Engines	all	-22%	138%	-54%	0%	0%	0%	0%	138%	0%
Associated Gas Venting	all	-69%	-69%	-69%	-69%	0%	0%	-69%	-69%	-69%
Drill Rigs	all	-42%	-35%	107%	0%	-77%	-77%	0%	-35%	0%
Hydraulic Fracturing Engines	all	-52%	-51%	106%	0%	-80%	-80%	0%	-51%	0%
Nonpoint Fugitives	added	0%	-50%	0%	0%	0%	0%	-50%	-50%	-50%
Pneumatic Devices	added	0%	-89%	0%	0%	0%	0%	-89%	-89%	-89%
Completions	all	16%	-87%	16%	0%	0%	0%	16%	-87%	16%
Williston, ND										
Artificial Lift Engines	all	-33%	15%	-14%	0%	0%	0%	0%	15%	0%
Associated Gas Venting	all	-69%	-69%	-69%	-69%	0%	0%	-69%	-69%	-69%
Drill Rigs	all	-42%	-38%	101%	0%	-78%	-78%	0%	-38%	0%
Hydraulic Fracturing Engines	all	-53%	-53%	99%	0%	-81%	-81%	0%	-53%	0%
Nonpoint Fugitives	added	0%	-50%	0%	0%	0%	0%	-50%	-50%	-50%
Pneumatic Devices	added	0%	-89%	0%	0%	0%	0%	-89%	-89%	-89%
Completions	all	8%	-78%	8%	0%	0%	0%	8%	-78%	8%
Williston, SD										
Associated Gas Venting	all	-69%	-69%	-69%	-69%	0%	0%	-69%	-69%	-69%
Permian, NM										
Condensate tank	added	0%	-95%	0%	0%	0%	0%	-95%	-95%	-95%
Nonpoint Fugitives	added	0%	-50%	0%	0%	0%	0%	-50%	-50%	-50%
Oil Tank	added	0%	-95%	0%	0%	0%	0%	-95%	-95%	-95%
Pneumatic Devices	added	0%	Gas wells: -90% Oil wells: -85%	0%	0%	0%	0%	Gas wells: -90% Oil wells: -85%	Gas wells: -90% Oil wells: -85%	0%
Venting - initial completions	all	56%	-96%	56%	0%	0%	0%	56%	-96%	56%
Green River, WY										
Condensate Tanks	all	-21%	-61%	-21%	0%	0%	0%	-21%	-21%	-21%
Well-head Engines	all	-25%	-11%	11%	-65%	-33%	30%	0%	-11%	0%
Pneumatic Pumps	all	-55%	-66%	-55%	0%	0%	0%	-66%	-66%	-66%
Nonpoint Fugitives	all	0%	-78%	0%	0%	0%	0%	-78%	-78%	-78%
Powder River, WY										
Well-head Engines	all	-37%	-45%	-52%	32%	486%	497%	0%	-45%	0%
Pneumatic Pumps	all	28%	26%	28%	0%	0%	0%	26%	26%	26%
Nonpoint Fugitives	all	0%	-47%	0%	0%	0%	0%	-47%	-47%	-47%
Denver Basin, WY										
Artificial Lift	added	-71%	-25%	-90%	-100%	-100%	-100%	0%	-25%	0%
Drill Rigs	all	-99%	-100%	-99%	-97%	-100%	-100%	0%	-100%	0%

Description	Applicability ¹	Percent Change in Emissions from Baseline Inventory								
		NO _x	VOC	CO	SO _x	PM ₁₀	PM _{2.5}	CO ₂	CH ₄	N ₂ O
Fugitives	added	0%	43%	0%	0%	0%	0%	43%	43%	43%
Completion	all	100%	162%	-100%	-100%	-100%	-100%	162%	162%	162%
Gas Well Venting - Blowdowns	added	0%	0%	0%	0%	0%	0%	0%	0%	0%
Heaters	added	-92%	-92%	-92%	-92%	-92%	-92%	-92%	-92%	-92%
Hydraulic Fracturing Engines	all	305%	46%	400%	1845%	3%	-14%	0%	46%	0%
Miscellaneous Engines	added	-71%	-25%	-90%	-100%	-100%	-100%	0%	-25%	0%
Oil Well Pneumatic Devices	added	0%	-85%	0%	0%	0%	0%	-85%	-85%	-85%
Oil Well Pneumatic Pumps	added	0%	0%	0%	0%	0%	0%	0%	0%	0%
Oil Well Tanks - Flashing & Standing/Working/Breathing	added	-53%	-79%	-53%	0%	0%	0%	-79%	-79%	-79%
Storage Tanks: Crude Oil	added	-53%	-79%	-53%	0%	0%	0%	-79%	-79%	-79%
Tank Truck/Railcar Loading: Condensate	added	-50%	-7%	-58%	0%	0%	0%	-7%	-7%	-7%
Tank Truck/Railcar Loading: Crude Oil	added	-50%	-7%	-58%	0%	0%	0%	-7%	-7%	-7%

¹ "Added" refers to O&G activity added between the baseline and future year. "All" refers to all O&G activity in future year 2028.

² Emission changes for the Denver Basin represent the change in emissions from legacy vertical wells in the base year inventory to new horizontal wells

³ Emission changes for the Green River and Powder River basins represent emission rate changes from the baseline inventory based on WYDEQ provided detailed wellsite emissions data for 2014 and 2017.

4.0 RESULTS SUMMARY

O&G emissions results for the future year 2028 O&G emission inventory for the WESTAR-WRAP region are presented below as a series of tables and charts. Additional summaries and fully detailed emission inventory data are available in spreadsheets that accompany this report which are posted on the WRAP OGWG website (<https://www.wrapair2.org/OGWG.aspx>).

4.1 Future Year 2028 WRAP OGWG v2 emission inventory

Future Year 2028 WRAP OGWG NOx and VOC emissions for all WRAP region basins are summarized in Table 4-1 and Table 4-2, respectively. Across the WESTAR-WRAP region, most nonpoint O&G emissions are emitted from wellsite sources and most point O&G emission are emitted from midstream sources. Approximately 45% of 2028 NOx emissions and over 85% of 2028 VOC emissions were from nonpoint sources. Basin specific nonpoint and point source contributions result from basin specific equipment and operational characteristics and infrastructure, and in some cases basin specific accounting. For example, the Uinta Basin includes several wellsite source categories in the point source emission inventory. The top-seven emitting basins account for approximately 89% of NOx emissions and the top-five basin and state combinations account for over 81% of VOC emissions.

Table 4-1. Summary of nonpoint and point NOx emissions (tons/yr) by basin.

Basin and State	NOx Emissions (tons/yr)		
	Nonpoint	Point	Total
Permian, NM	19,989	43,488	63,478
Williston, ND	31,888	12,184	44,072
San Juan, NM	30,167	6,680	36,847
Arctic Coastal Plains Province, AK	1,204	29,883	31,087
Powder River, WY	7,236	3,098	10,335
Green River, WY	4,663	5,189	9,852
Uinta, UT	728	8,695	9,423
AK Cook Inlet Basin, AK	1,612	4,058	5,670
Williston, MT	1,573	1,134	2,706
Sweetgrass, MT	1,820	233	2,053
Big Horn, WY	683	1,223	1,906
Plateau Sedimentary Prov, AZ	-	1,468	1,468
Wind River, WY	216	1,142	1,359
Williston, SD	357	867	1,225
Paradox, UT	699	321	1,020
Central Montana Uplift, MT	411	560	971
Denver Basin noCO, WY	711	171	882
Orogrande Basin, NM	1	540	541
Central Western Overthrust, ID	0	466	466
Other WRAP Basins	338	3706	4044
Total	104,297	125,106	229,403

Table 4-2. Summary of nonpoint and point VOC emissions (tons/yr) by Basin.

Basin and State	VOC Emissions (tons/yr)		
	Nonpoint	Point	Total
Williston, ND	240,549	4,292	244,841
Permian, NM	124,129	26,156	150,285
San Juan, NM	70,590	4,036	74,626
Powder River, WY	53,047	2,877	55,923
Uinta, UT	3,994	51,285	55,279
Green River, WY	30,118	10,848	40,965
Williston, MT	26,297	1,659	27,956
Arctic Coastal Plains Province, AK	18,512	584	19,096
Paradox, UT	11,823	52	11,874
Williston, SD	7,938	26	7,963
Wind River, WY	5,613	1,220	6,833
AK Cook Inlet Basin, AK	4,100	566	4,665
Sweetgrass, MT	4,501	77	4,578
Denver Basin, WY	3,212	1,008	4,220
Big Horn, WY	2,559	418	2,977
Central Montana Uplift, MT	1,800	59	1,859
Raton, NM	646	-	646
Overthrust & Wasatch Uplift, UT	505	-	505
Powder River, MT	347	6	354
Great Basin Province, NV	219	50	269
Other WRAP Basins	656	465	1,120
Total	611,153	105,682	716,834

4.2 Future Year 2028 Comparison to circa-2014 Baseline Emission Inventories

Changes from the circa-2014 baseline WRAP OGWG v2 to the 2028 future year inventory are shown below for NO_x (Figure 4-1) and VOC (Figure 4-2).

Changes from the circa-2014 baseline to the future year emission inventory are based on estimated change in O&G activity and emission control effects from the baseline to future year. WESTAR-WRAP region-wide NO_x emissions decreased by 14% and VOC emissions decreased by 24%.

NO_x emission decreases for Wyoming, Utah, and Alaska are due to declines in O&G activity from the baseline year to the future year. NO_x emission decreases for North Dakota and Montana result from decreases in Williston Basin drilling activity from the baseline to the future year inventory and application of control factors to drilling engines, fracturing engines, and artificial lift engines. Permian Basin NO_x emission increases result from increases to O&G activity from the baseline to future year.

VOC emission decreases for Alaska are based on decreases to O&G activity from the baseline to the future year. Permian Basin NO_x emission increases result from increases to O&G activity from the baseline to future year. VOC emission decreases in North Dakota, Montana, and South Dakota result from the assumption that a higher percentage of associated gas is sent to pipeline compared to the baseline (i.e., lower percentage of associated gas is flared or vented) and NSPS Subpart OOOO and OOOOa control program requirements for pneumatic controls and completions. VOC emission decreases for Utah result from control effects of Utah O&G wellsite permitting programs which affect new and existing sources as well as O&G activity declines.

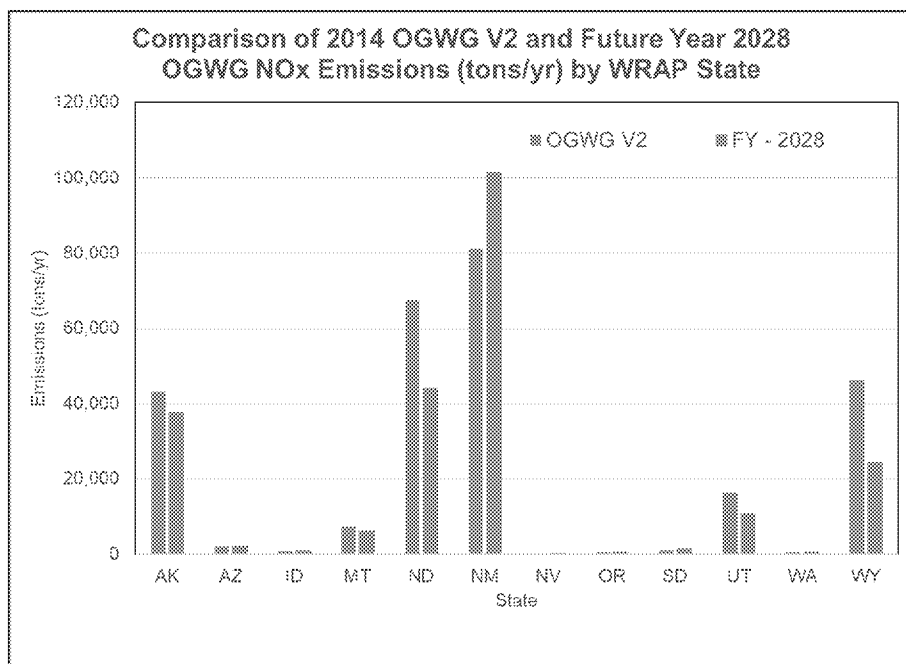


Figure 4-1. Comparison of 2014 OGWG V2 and Future Year 2028 NOx emissions by WRAP region State.

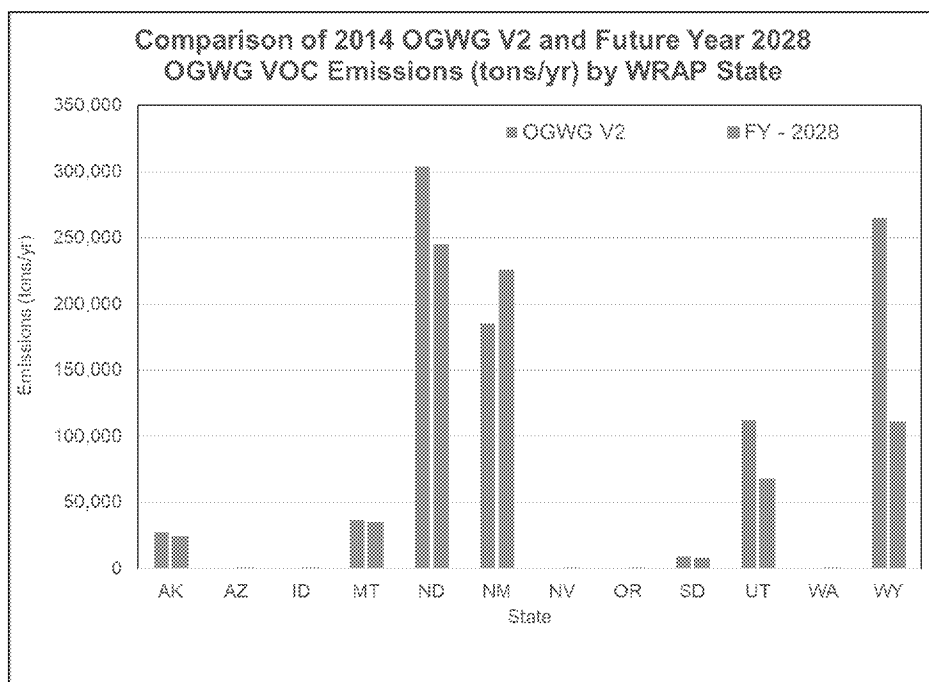


Figure 4-2. Comparison of 2014 OGWG V2 and Future Year 2028 VOC emissions by WRAP region State.

5.0 REFERENCES

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APPENDIX A

Scenario 1: Continuation of Historical Trends O&G Activity Forecast Details

O&G activity forecasts were developed for Scenario 1 for select WRAP O&G basins by extending recent historical oil and gas activity trends to future year 2023. O&G activity forecasts were developed for well count, gas production, and oil production by basin, spud type (vertical, horizontal, or directional) and well type (oil, gas, coalbed methane [CBM]); spud count forecasts were developed by basin and spud type. Trends in O&G activity for recent historical years (typically within the most recent 5 year period 2013-2017) were extended to future year 2023. Forecast methodology for each parameter, basin, spud type, and well type was chosen based on a review of recent trends and application of engineering judgement to estimate the historical year period to extend and the forecast method to assume. State agencies reviewed the methodology and forecasts during and subsequent to a series of late-March 2019 teleconferences²⁰ in which the forecasts were presented. A description of forecast methods is shown in Table 1. Tables 2 and 3 show forecasting methodologies that were applied for each parameter in each basin.

Table 1. Summary of Forecasting Methods

Methodology	Indicator	Description
Default	d	Forecast based on average of the previous 5 years
Truncated Default	#d	Forecast based on average of previous # years
Linear Forecast	#L	Linear forecast based on previous # years
Last	Last	Forecast same as most recent year of production available
Percent Differential	%	Forecast assumes annual % decline at a rate equal to the percent decline in previous # years
Percent Reduction	#r	Forecast assumes % decline over future period (2018-2023) is equal to % decline over # year time period

Table 2. Summary of Applied Production Forecast Methods by Basin

Basin (State)	Vertical			Horizontal			Directional		
	Well Count	Oil Production	Gas Production	Well Count	Oil Production	Gas Production	Well Count	Oil Production	Gas Production
Oil Wells									
Denver Basin (WY)	Last	Last	Last	5L	5L	5L	d	Last	Last
Sweetgrass Basin (MT)	d	5%	Last	d	d	d	d	3d	d
Williston Basin (MT,ND,SD)	5L	2%	4L	4L	d	5L	d	4L	Last
Permian Basin (NM)	5L	Last	4L	5L	3%	5L	d	d	d
San Juan Basin (NM,CO)	5L	Last	5%	5L	4d	4d	d	Last	d
Paradox Basin (CO,UT)	5%	3%	d	d	Last	d	Last	5%	Last
Uinta Basin (UT)	5r	1%	5%	Last	3%	3%	d	d	Last
Big Horn Basin (WY)	5L	5%	d	d	d	d	4L	5L	d
Green River Basin (WY)	Last	Last	d	d	d	d	d	3d	d
Powder River Basin (WY)	2%	5%	2%	5L	Last	d	d	d	d

²⁰ March 18, 2019 Northern Basins teleconference; March 19, 2019 Central Basins teleconference; March 20, 2019 Southern Basins teleconference; and March 21, 2019 Alaska Basins teleconference.

Basin (State)	Vertical			Horizontal			Directional		
	Well Count	Oil Production	Gas Production	Well Count	Oil Production	Gas Production	Well Count	Oil Production	Gas Production
Wind River Basin (WY)	Last	Last	d	d	4d	Last	d	d	4L
Gas Wells									
Denver Basin (WY)	-	-	-	-	-	-	-	-	-
Sweetgrass Basin (MT)	5L	Last	Last	d	Last	Last	d	Last	5%
Williston Basin (MT,ND,SD)	4L	d	5%	d	5%	d	d	d	d
Permian Basin (NM)	5L	3%	Last	5L	3L	3L	d	d	Last
San Juan Basin (NM,CO)	5L	5%	5L	d	Last	Last	d	2%	5%
Paradox Basin (CO,UT)	d	5%	d	d	d	Last	d	5%	5%
Uinta Basin (UT)	5L	5r	5%	d	d	d	Last	4%	5%
Big Horn Basin (WY)	5L	d	5%	d	3L	3L	d	5%	5%
Green River Basin (WY)	5L	3%	Last	3%	Last	Last	3%	d	d
Powder River Basin (WY)	5L	5%	5%	Last	Last	d	d	4d	3%
Wind River Basin (WY)	d	4d	5%	d	Last	Last	d	Last	Last
CBM Wells									
Denver Basin (WY)	-	-	-	-	-	-	-	-	-
Sweetgrass Basin (MT)	d	-	d	d	-	d	d	-	d
Williston Basin (MT,ND,SD)	d	-	d	d	-	d	d	-	d
Permian Basin (NM)	-	-	-	-	-	-	-	-	-
San Juan Basin (NM,CO)	5L	-	5%	5L	-	d	5L	-	5%
Paradox Basin (CO,UT)	d	-	Last	d	-	Last	d	-	5L
Uinta Basin (UT)	d	-	5%	d	-	d	d	-	3%
Big Horn Basin (WY)	-	-	-	-	-	-	-	-	-
Green River Basin (WY)	3%	-	Last	d	-	d	d	-	Last
Powder River Basin (WY)	3%	-	1%	d	-	Last	d	-	Last
Wind River Basin (WY)	Last	-	d	d	-	d	d	-	Last

Table 3. Summary of Spud Count Forecast Methods by Basin

Basin (State)	Vertical	Horizontal	Directional
Spud Count			
Denver Basin (WY)	-	d	-
Sweetgrass Basin (MT)	d	d	d
Williston Basin (MT,ND,SD)	4d	Last	d
Permian Basin (NM)	Last	d	3d
San Juan Basin (NM,CO)	3d	Last	Last
Paradox Basin (CO,UT)	Last	Last	d
Uinta Basin (UT)	Last	Last	Last
Big Horn Basin (WY)	d	d	d
Green River Basin (WY)	Last	Last	3d
Powder River Basin (WY)	Last	3d	Last
Wind River Basin (WY)	3d	d	d

To illustrate the forecast methodology, Williston Basin methods and charts are included below with descriptions of forecasts by parameter, spud type, and well type for the most important parameters (forecast methods for all parameters may be found in Tables 2 and 3 above).

- **Spud Count (Figure 1):** Horizontal spud count for the most recent year was assumed for 2023 as no clear trend can be seen over the historical period.
- **Primary Gas Production (Figure 2):** Continued steady decline in primary gas production from vertical wells was assumed based on application of a five-year linear forecast (5L). Primary gas production from horizontal wells was assumed to remain steady at recent levels based on application of the average over the most recent 5 year historical period .
- **Associated Gas Production (Figure 3):** Continued increases in associated gas production from horizontal wells was estimated based on a five-year linear forecast (5L).
- **Condensate Production (Figure 4):** Continued steady decline in condensate from horizontal wells was assumed based on application of a five-year linear forecast (5L).
- **Oil Production (Figure 5):** Average oil production from horizontal wells over the most recent 5 years was assumed for 2023 as no clear trend can be seen over the historical period.
- **Gas Well Count (Figure 6):** Continued steady decline in vertical gas well counts were assumed based on application of a four-year linear forecast (4L).
- **Oil Well Count (Figure 7):** Continued increases in horizontal oil well counts were estimated based on a four-year linear forecast (4L). Continued steady decline in horizontal oil well counts were assumed based on application of a five-year linear forecast (5L).

Figures 8 through 51 below show historical trends and forecast O&G activity for each basin and parameter (spud count, well count, gas production, and oil production) by spud type (vertical, horizontal, and directional).

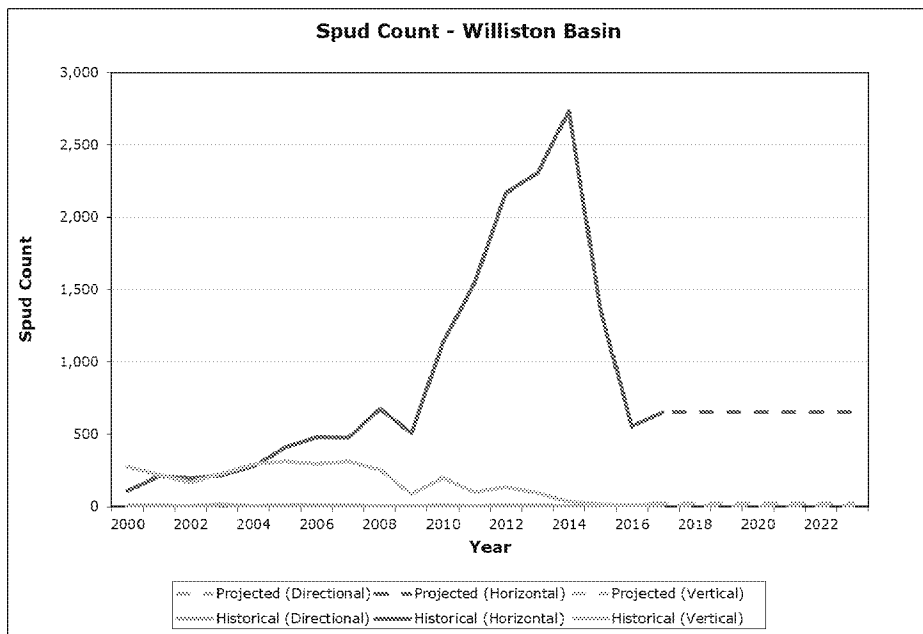


Figure 1. Williston Basin - Spud Count

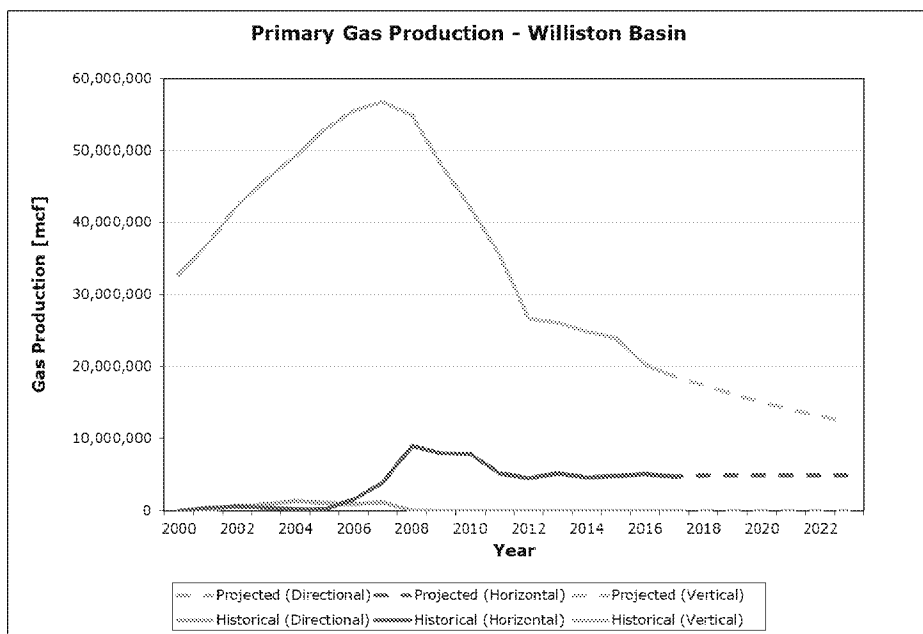


Figure 2. Williston Basin - Primary Gas Production

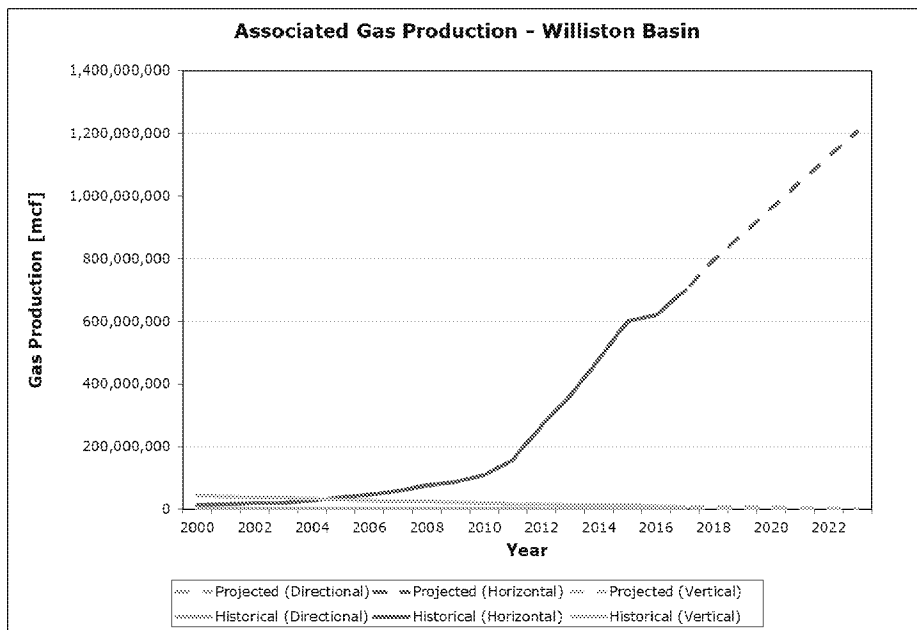


Figure 3. Williston Basin - Associated Gas Production

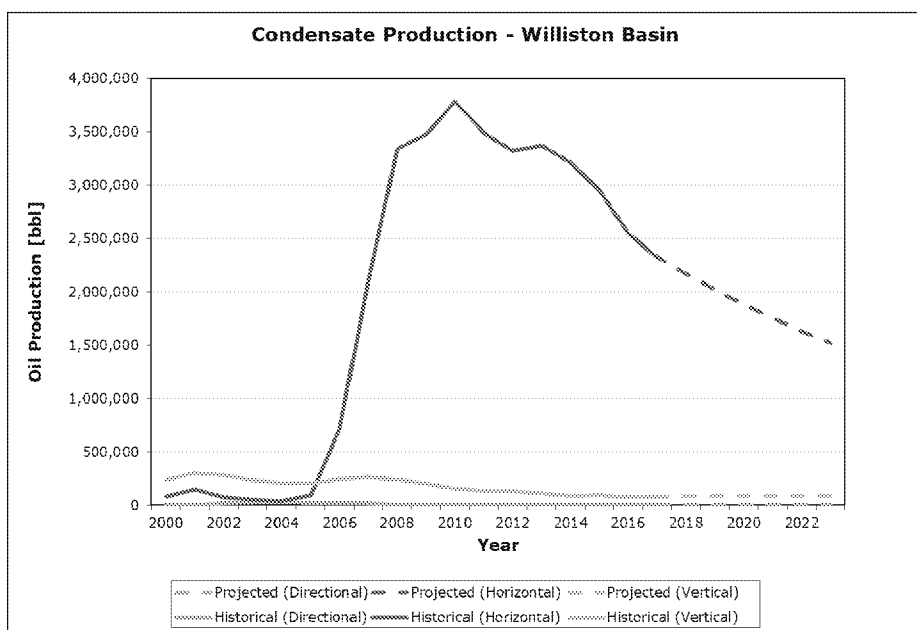


Figure 4. Williston Basin – Condensate Production

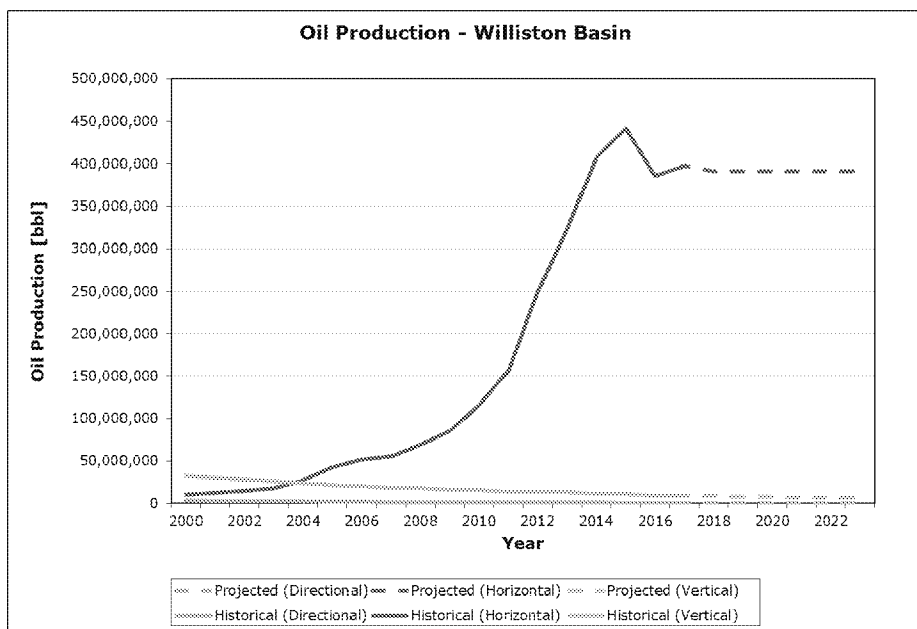


Figure 5. Williston Basin – Oil Production

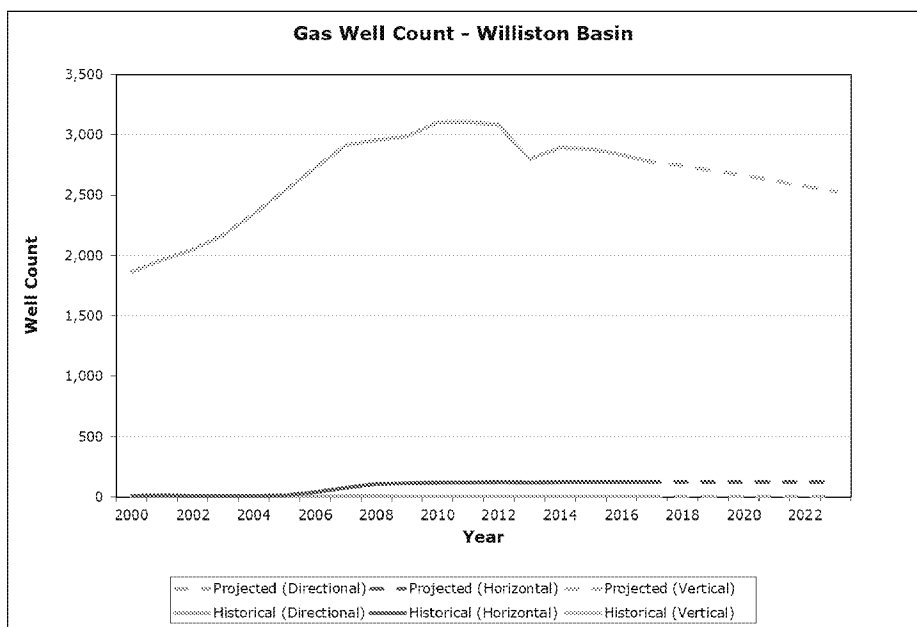


Figure 6. Williston Basin – Gas Well Count

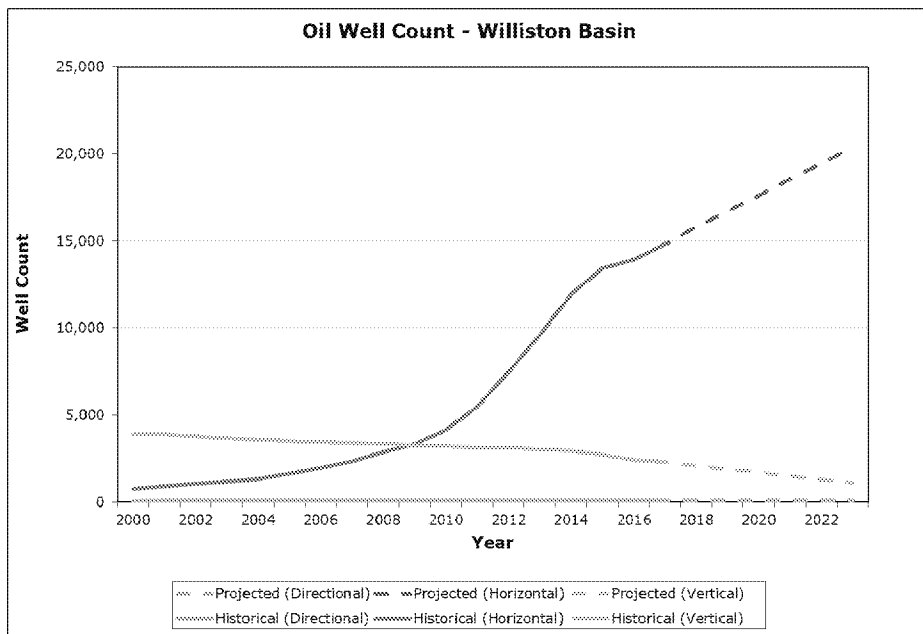


Figure 7. Williston Basin – Oil Well Count

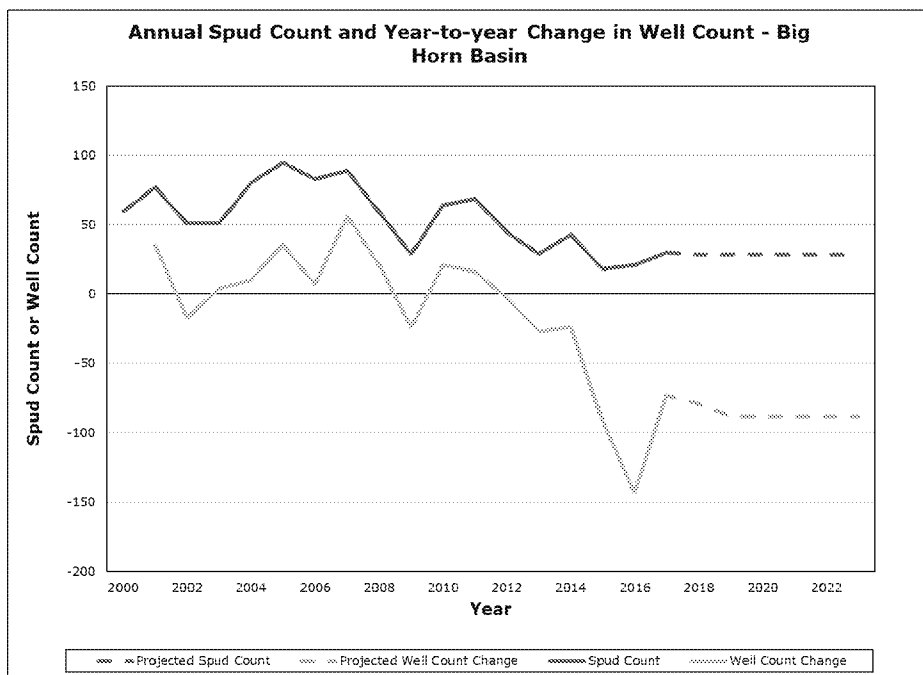


Figure 8. Big Horn Basin - Annual Spud Count and Year-Over-Year Change in Well Count

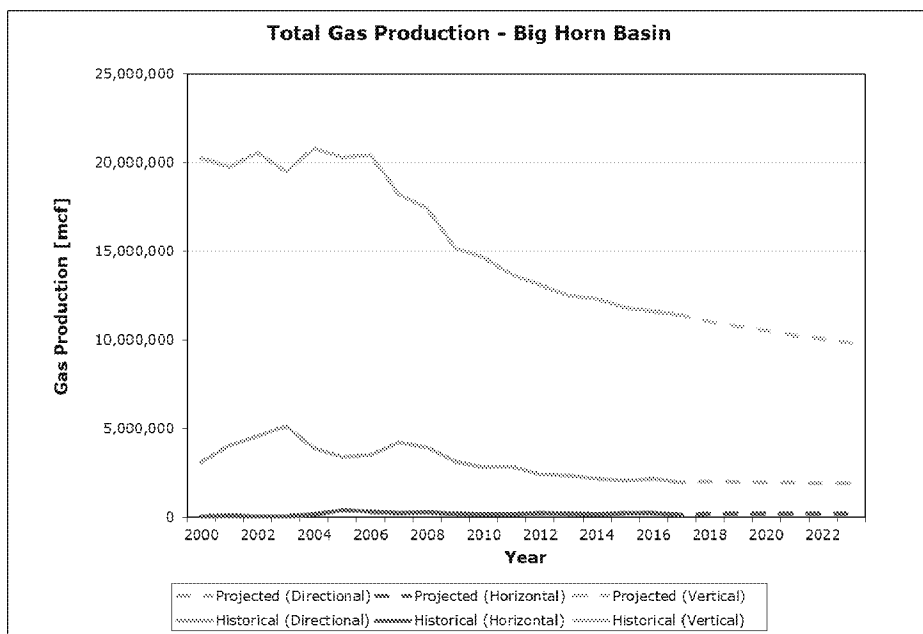


Figure 9. Big Horn Basin - Total Gas Production

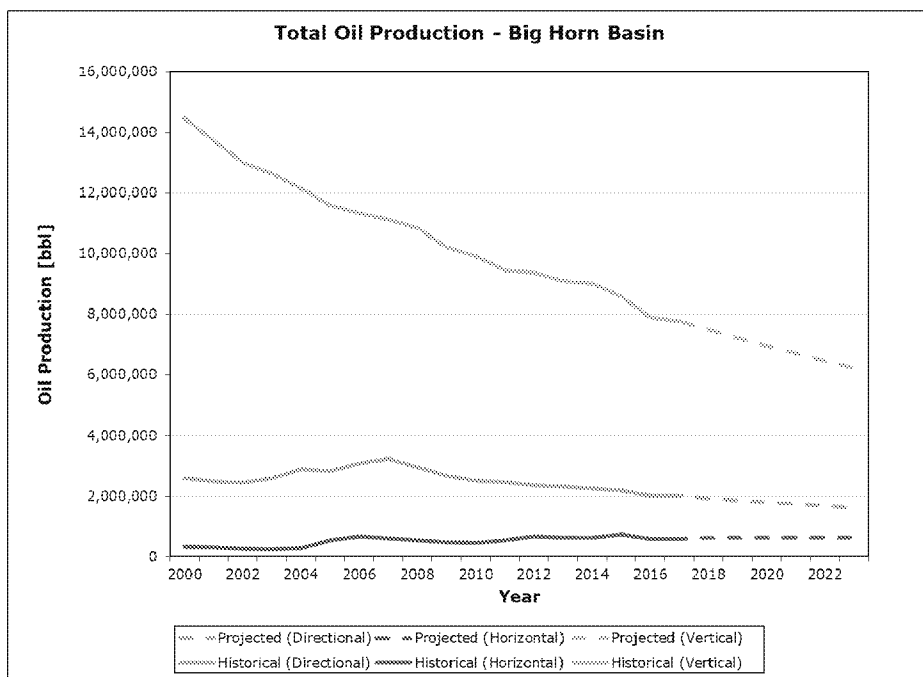


Figure 10. Big Horn Basin - Total Oil Production

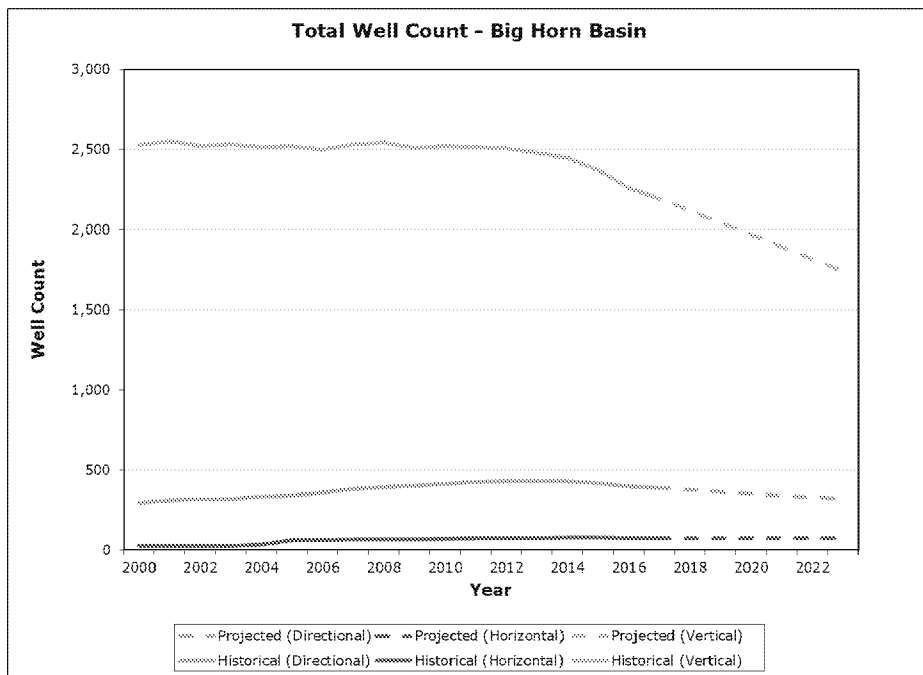


Figure 11. Big Horn Basin - Total Well Count

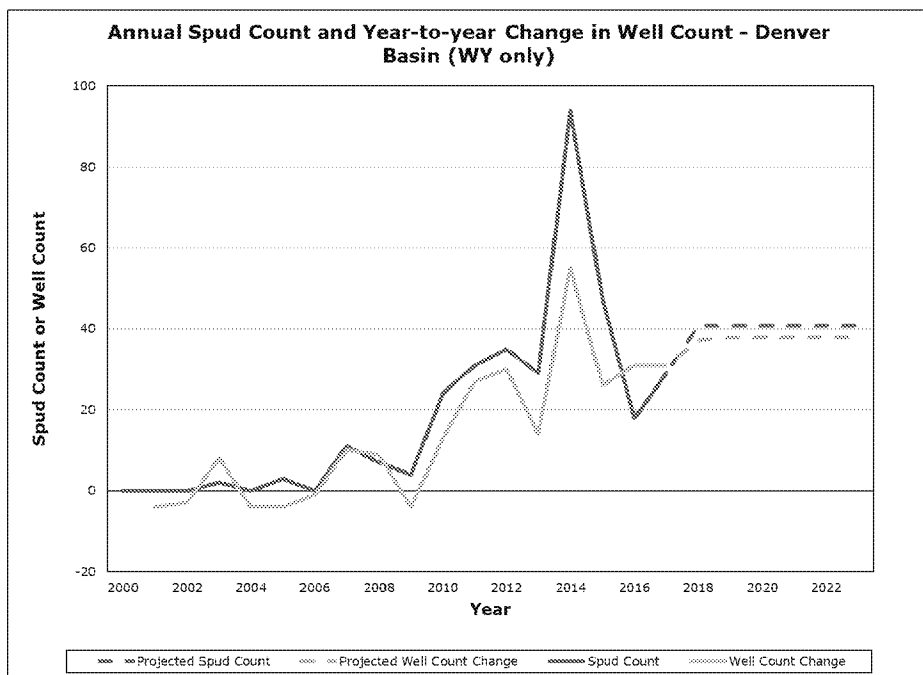


Figure 12. Denver Basin (Wyoming only) - Annual Spud Count and Year-Over-Year Change in Well Count

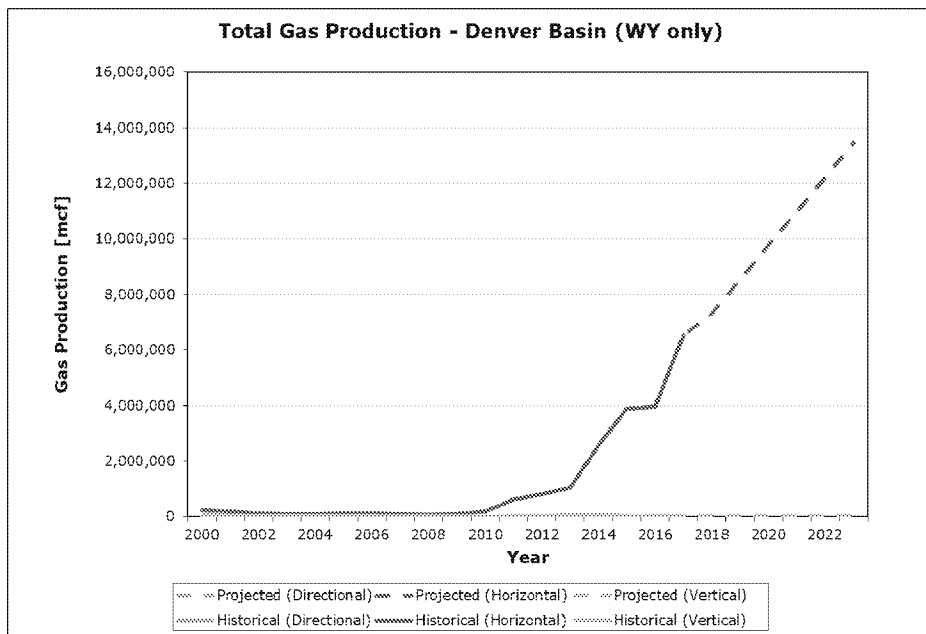


Figure 13. Denver Basin (Wyoming only) - Total Gas Production

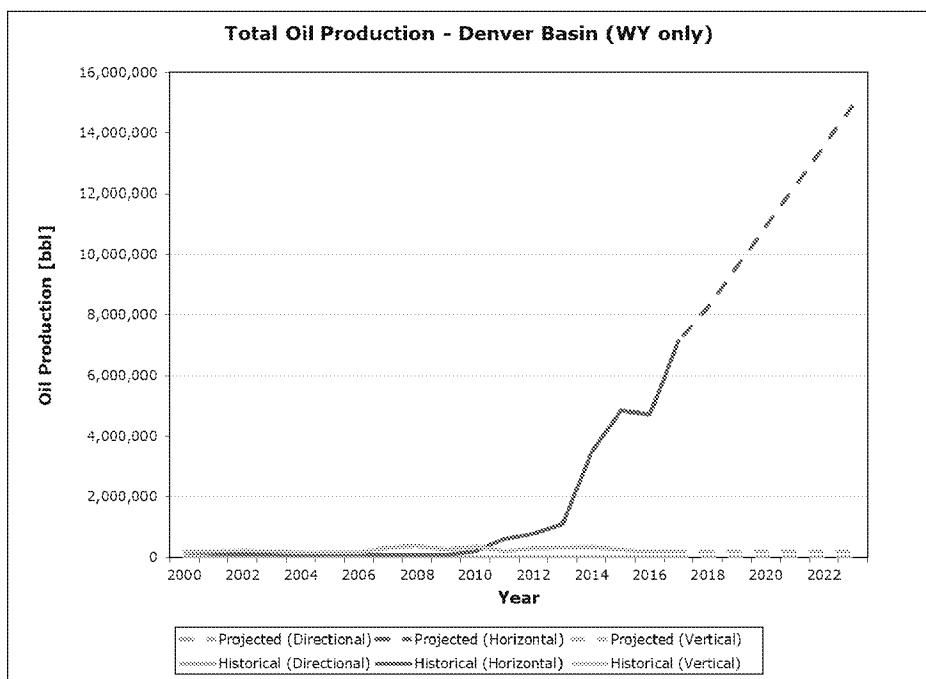


Figure 14. Denver Basin (Wyoming only) - Total Oil Production

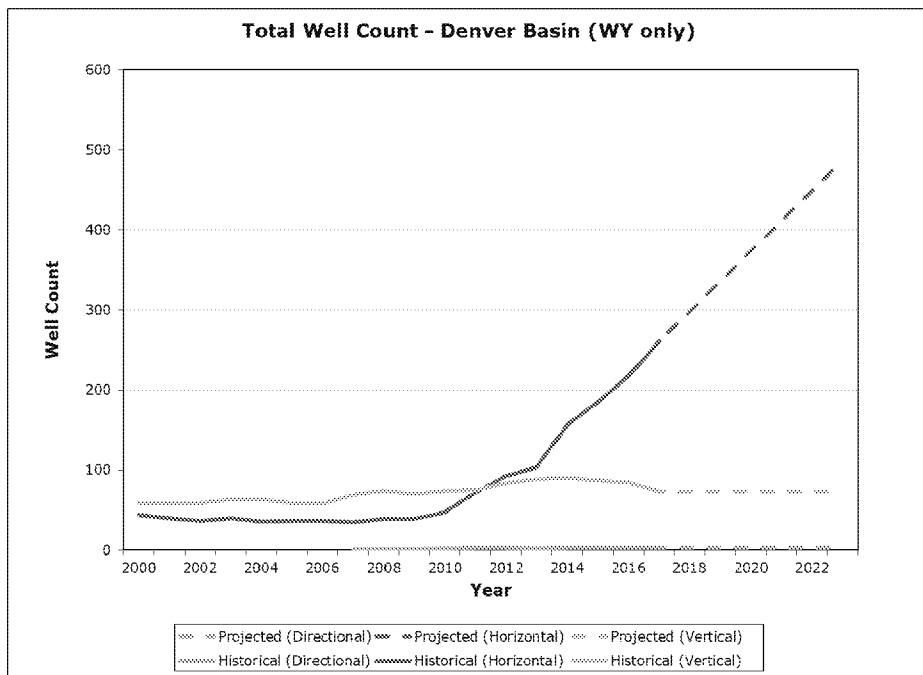


Figure 15. Denver Basin (Wyoming only) - Total Well Count

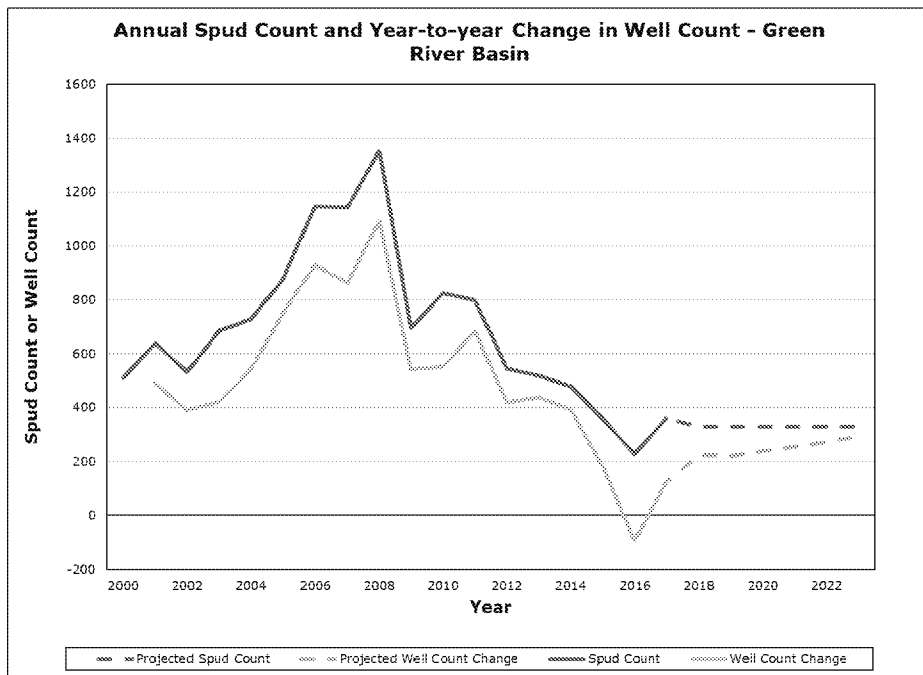


Figure 16. Green River Basin - Annual Spud Count and Year-Over-Year Change in Well Count

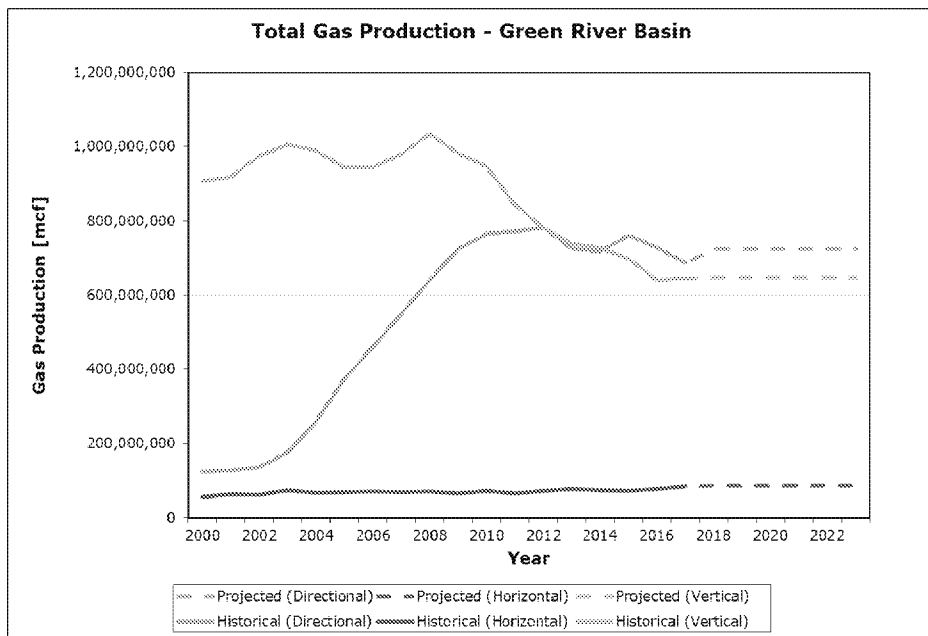


Figure 17. Green River Basin - Total Gas Production

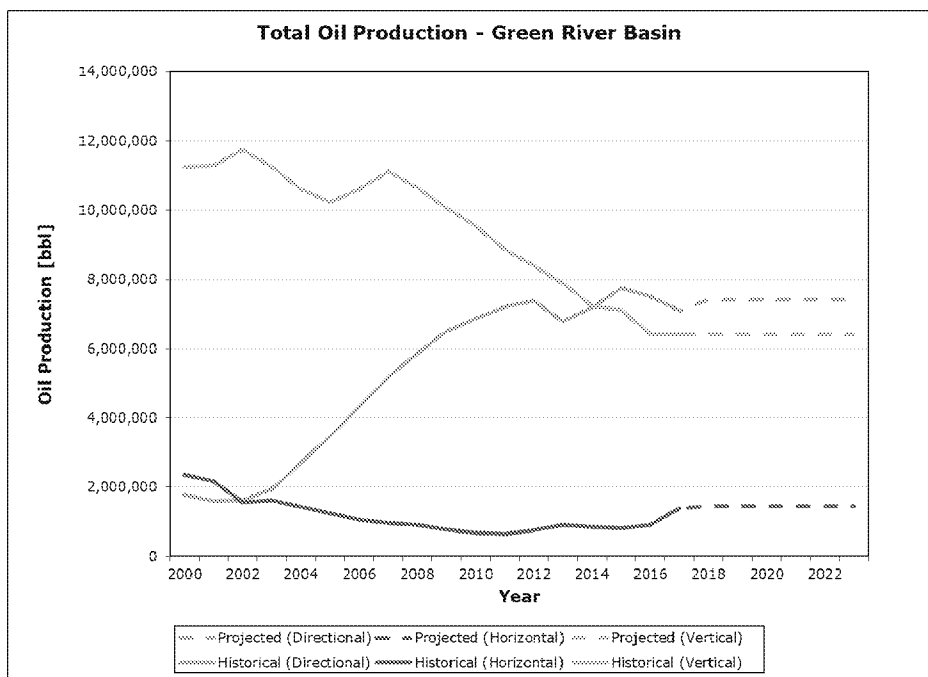


Figure 18. Green River Basin - Total Oil Production

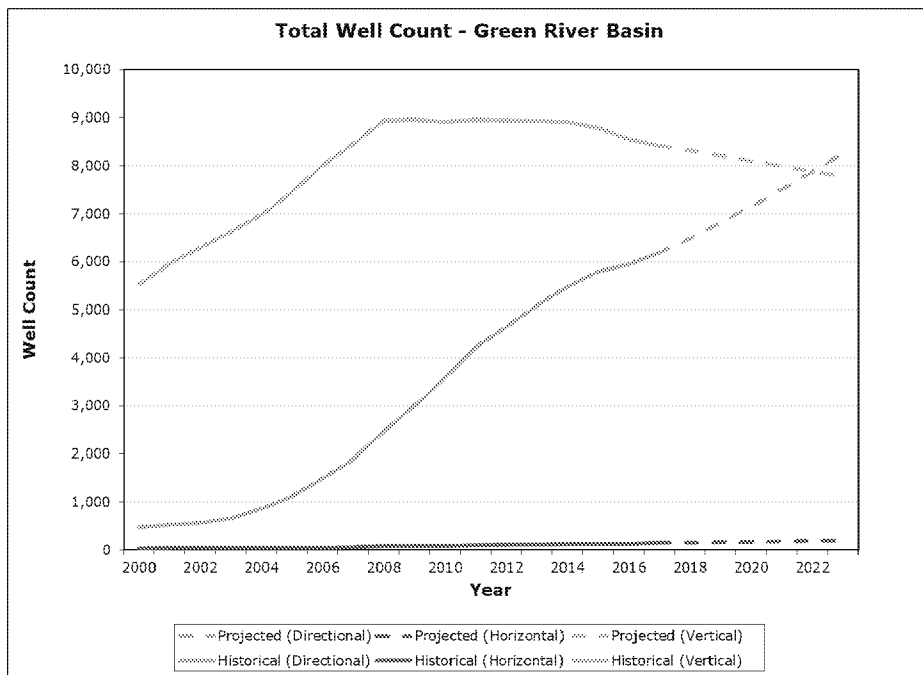


Figure 19. Green River Basin - Total Well Count

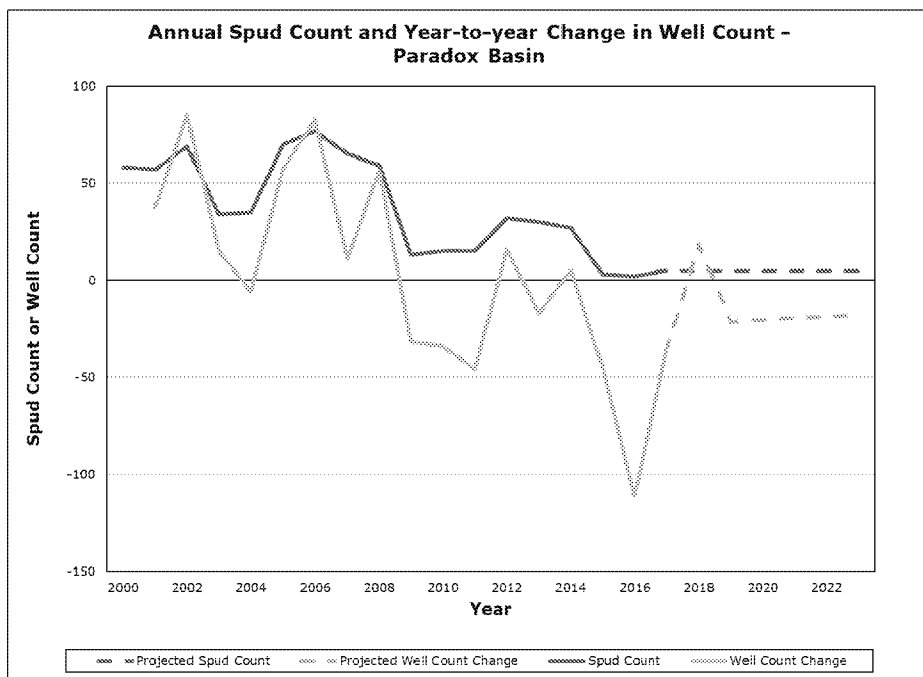


Figure 20. Paradox Basin - Annual Spud Count and Year-Over-Year Change in Well Count

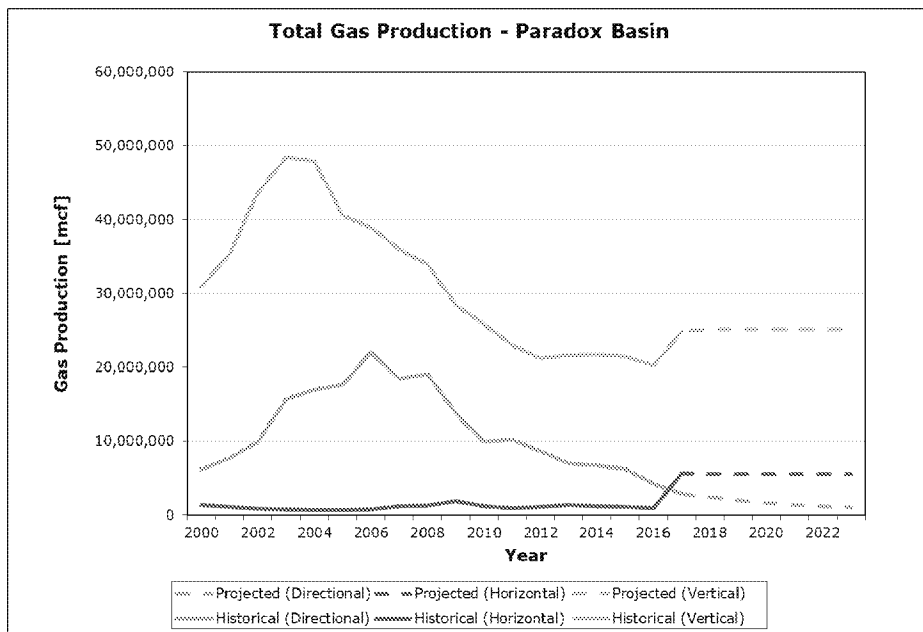


Figure 21. Paradox Basin - Total Gas Production

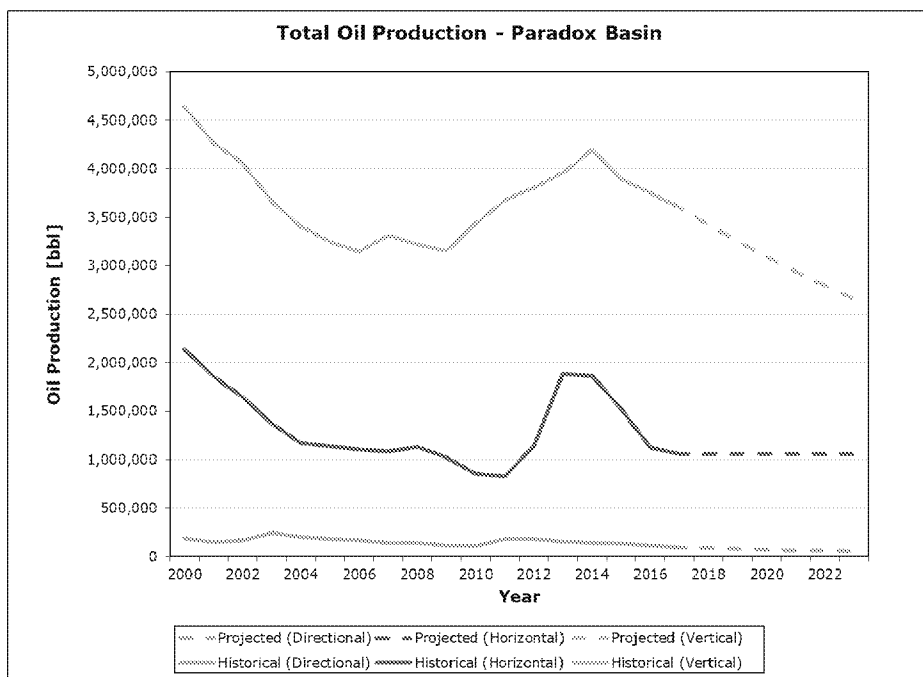


Figure 22. Paradox Basin - Total Oil Production

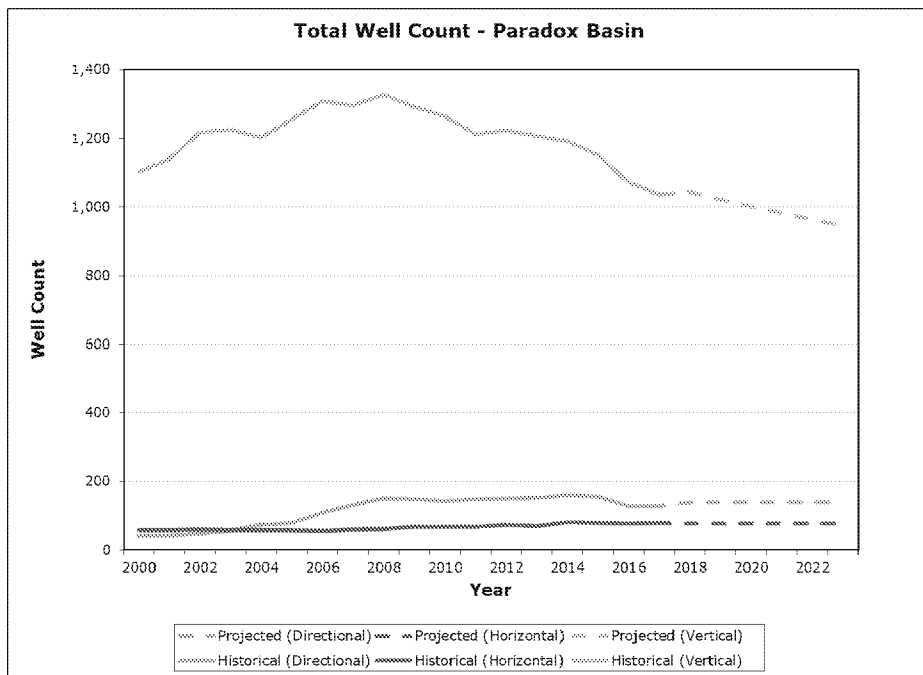


Figure 23. Paradox Basin - Total Well Count

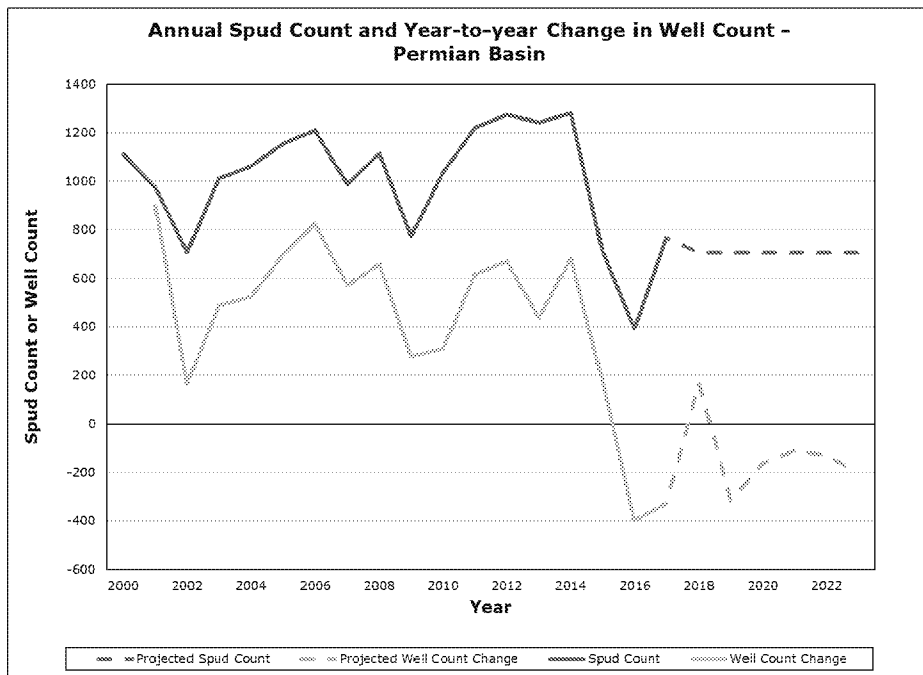


Figure 24. Permian Basin - Annual Spud Count and Year-Over-Year Change in Well Count

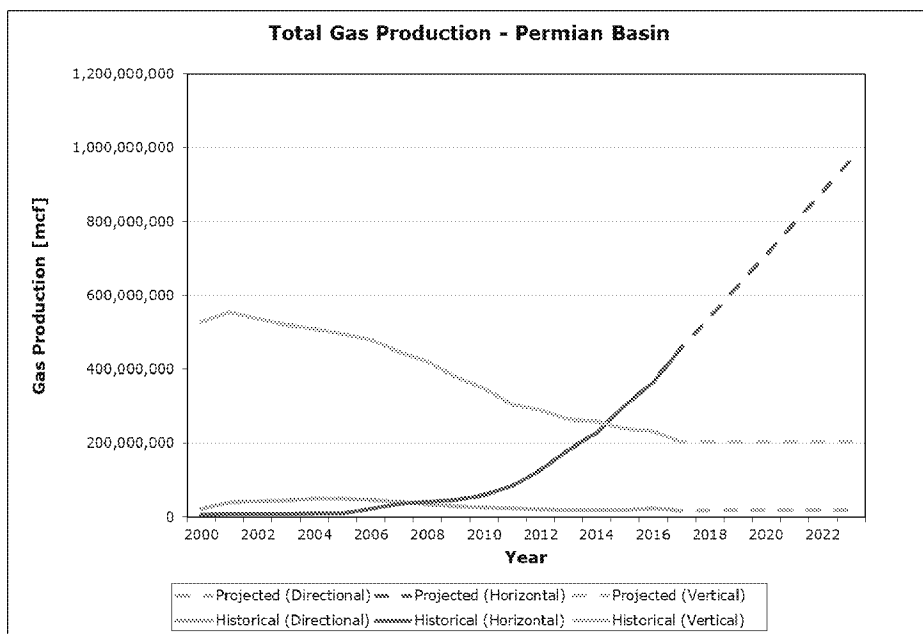


Figure 25. Permian Basin - Total Gas Production

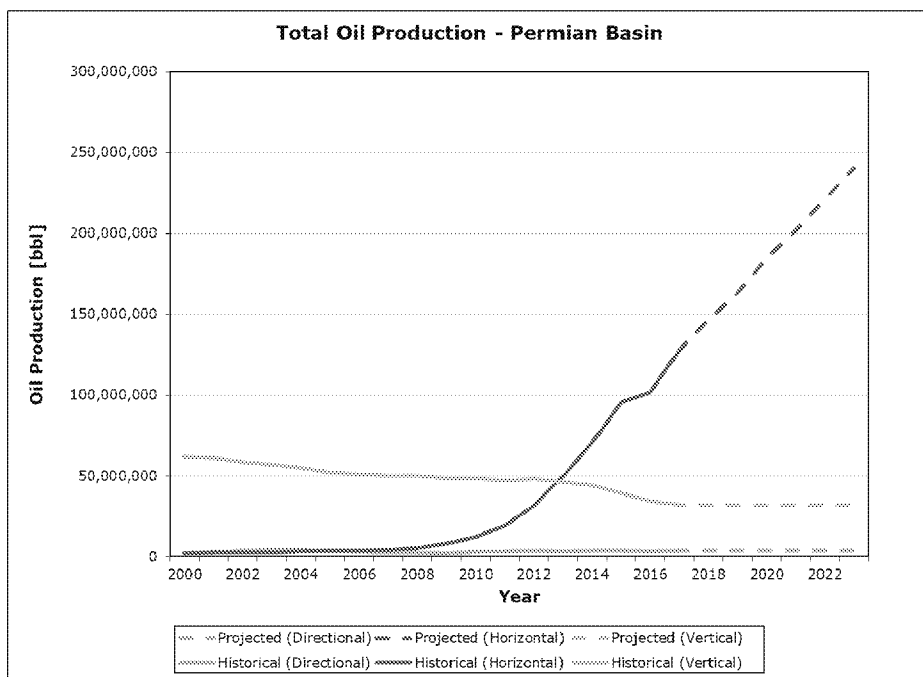


Figure 26. Permian Basin - Total Oil Production

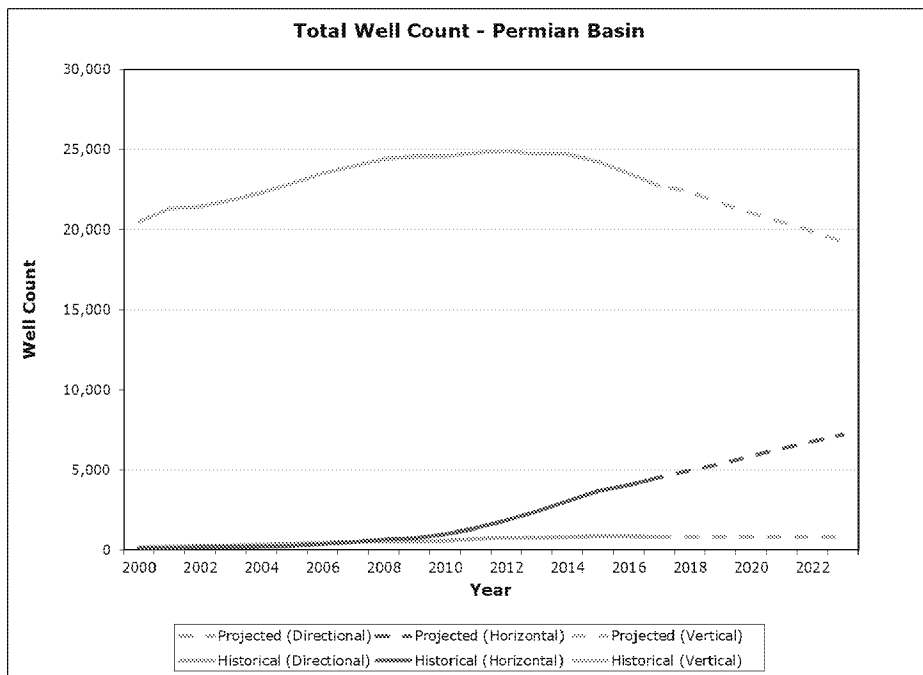


Figure 27. Permian Basin - Total Well Count

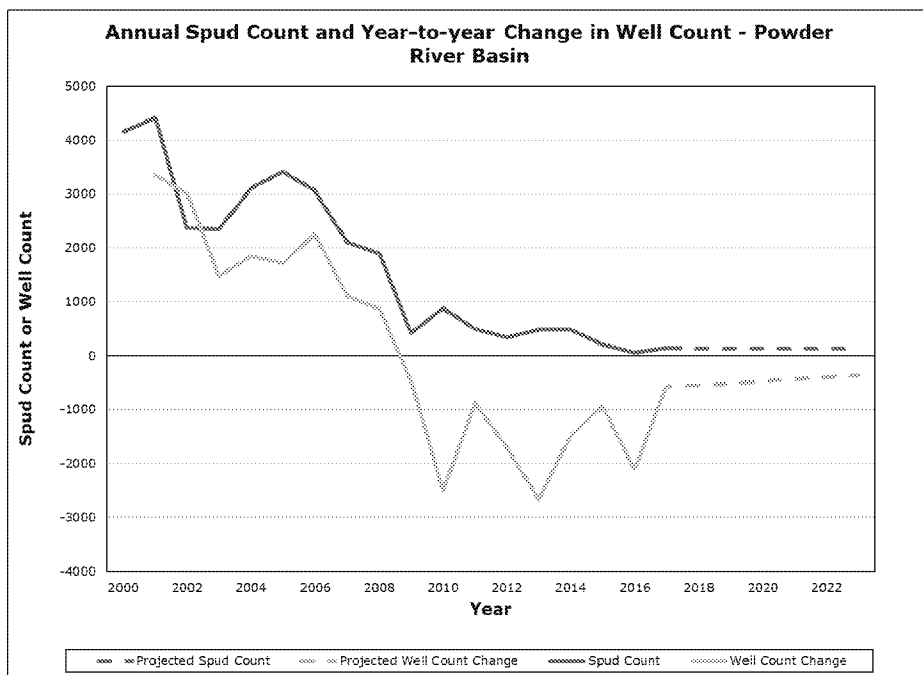


Figure 28. Powder River Basin - Annual Spud Count and Year-Over-Year Change in Well Count

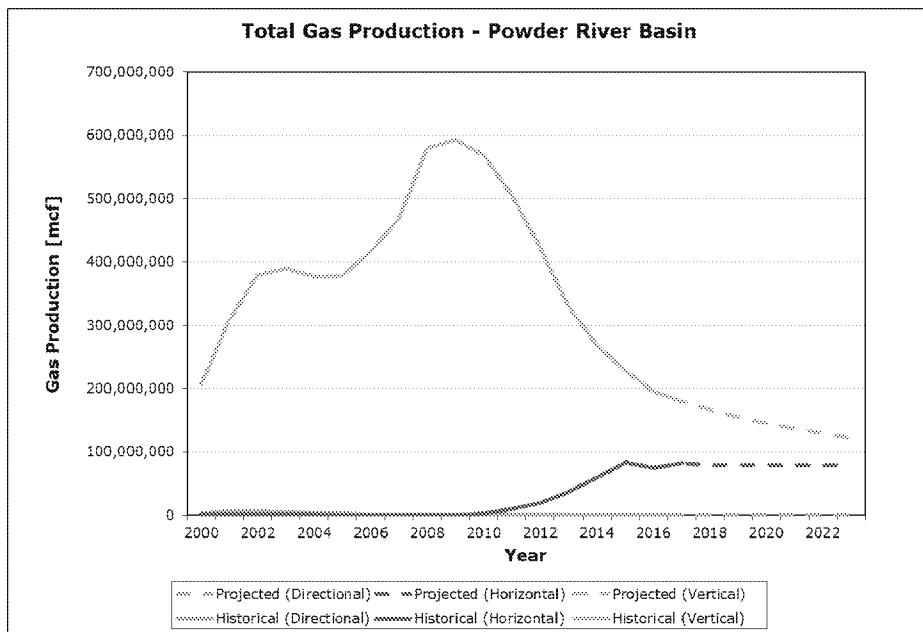


Figure 29. Powder River Basin - Total Gas Production

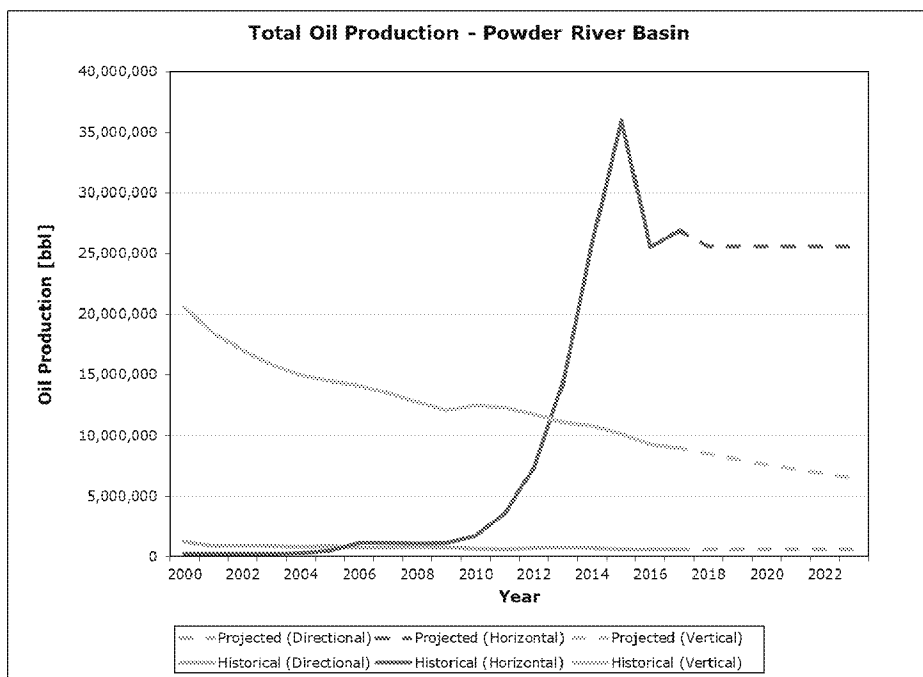


Figure 30. Powder River Basin - Total Oil Production

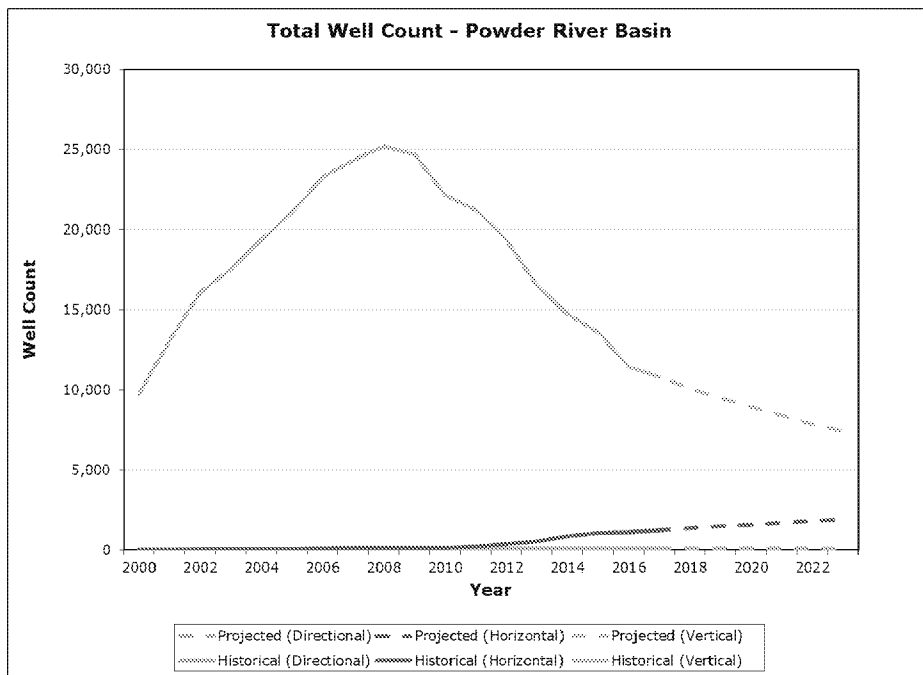


Figure 31. Powder River Basin - Total Well Count

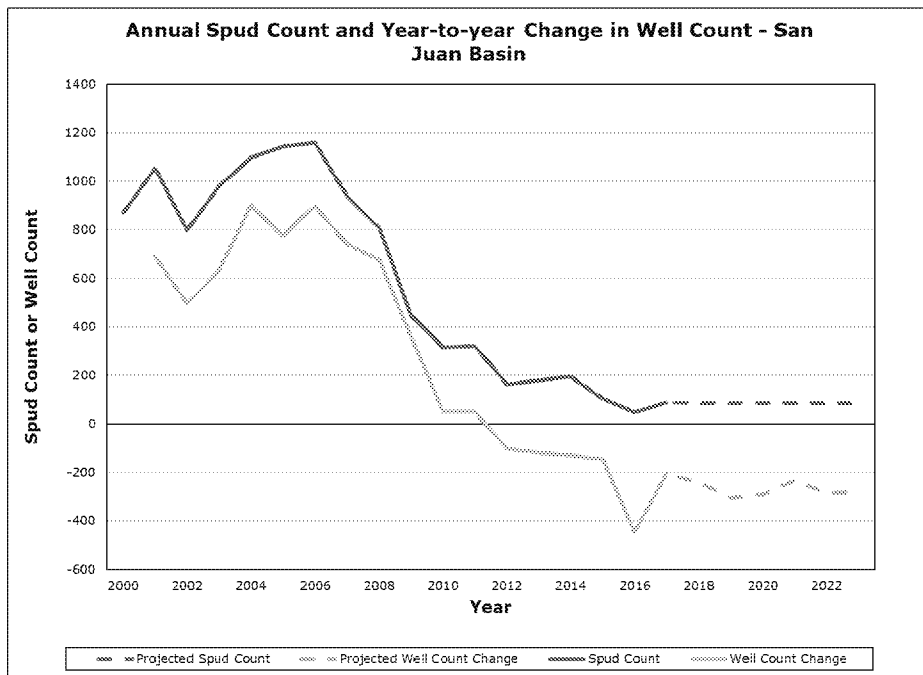


Figure 32. San Juan Basin - Annual Spud Count and Year-Over-Year Change in Well Count

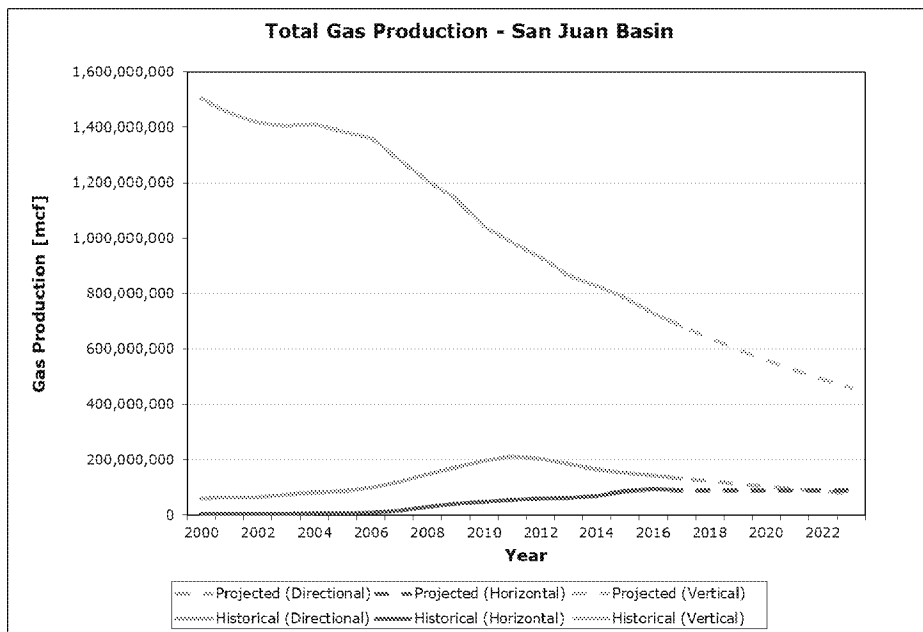


Figure 33. San Juan Basin - Total Gas Production

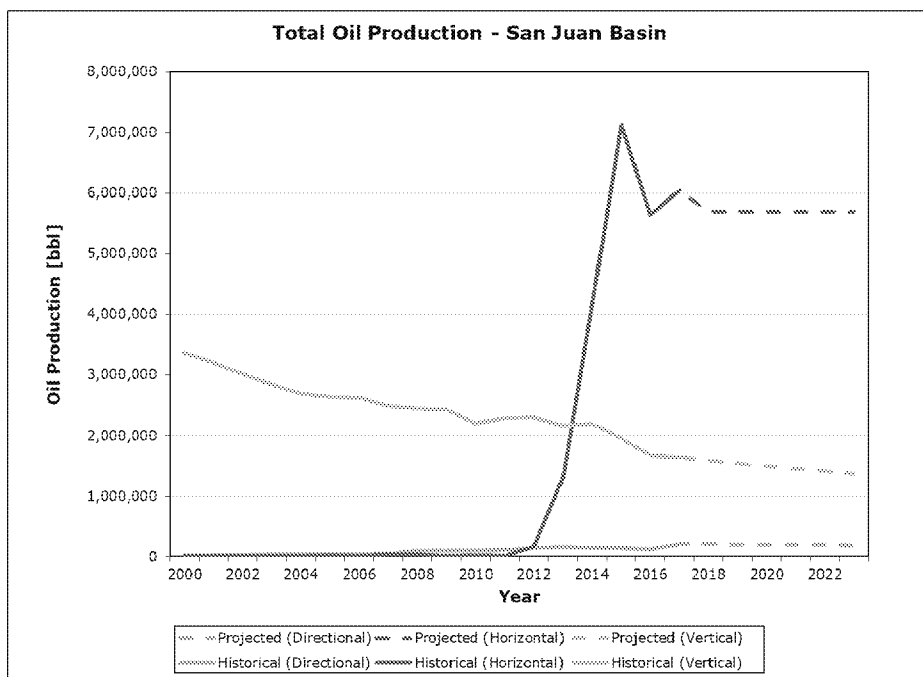


Figure 34. San Juan Basin - Total Oil Production

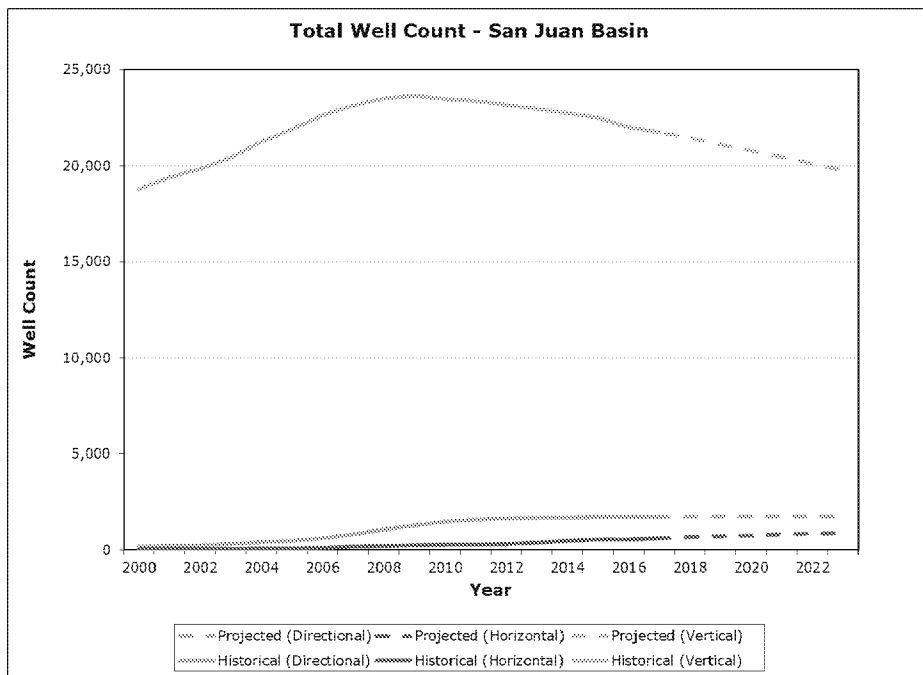


Figure 35. San Juan Basin - Total Well Count

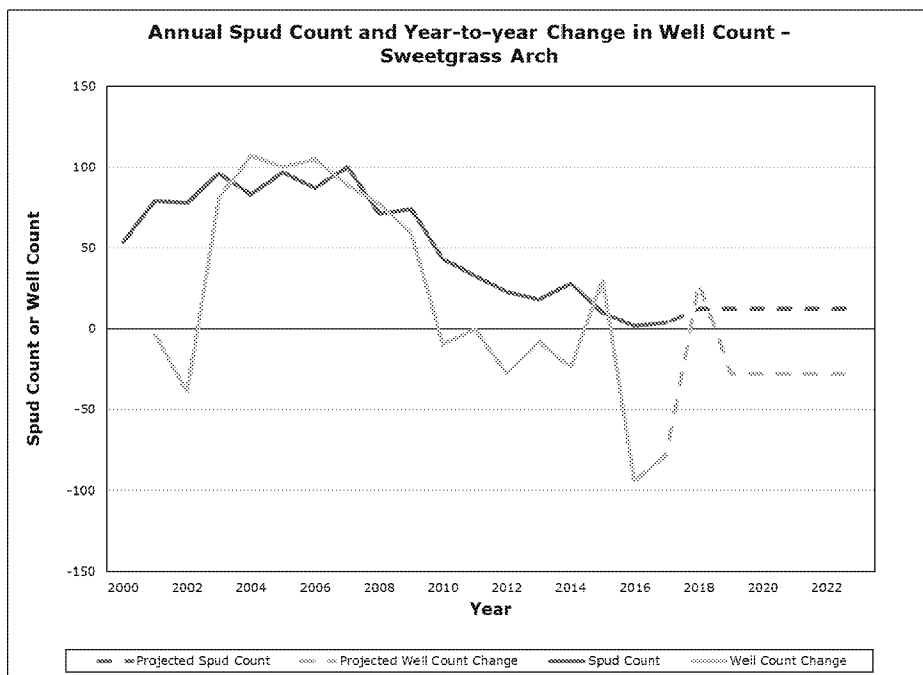


Figure 36. Sweetgrass Basin - Annual Spud Count and Year-Over-Year Change in Well Count

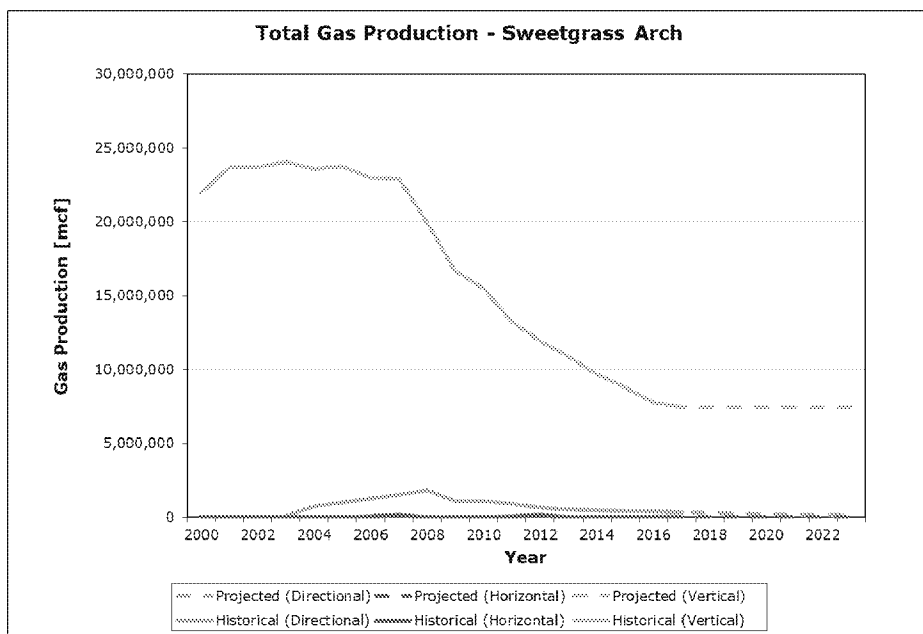


Figure 37. Sweetgrass Basin - Total Gas Production

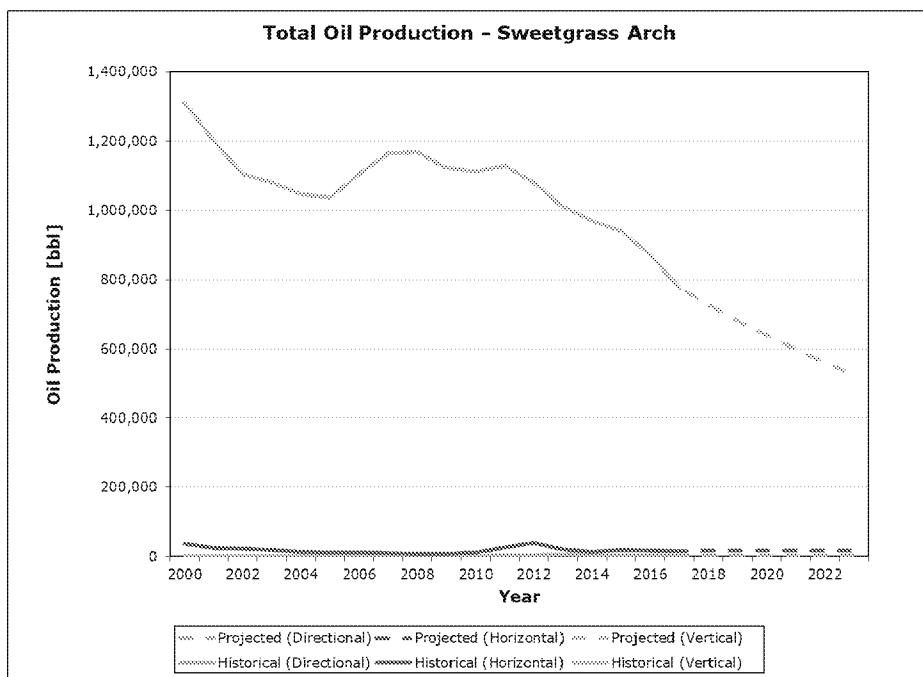


Figure 38. Sweetgrass Basin - Total Oil Production

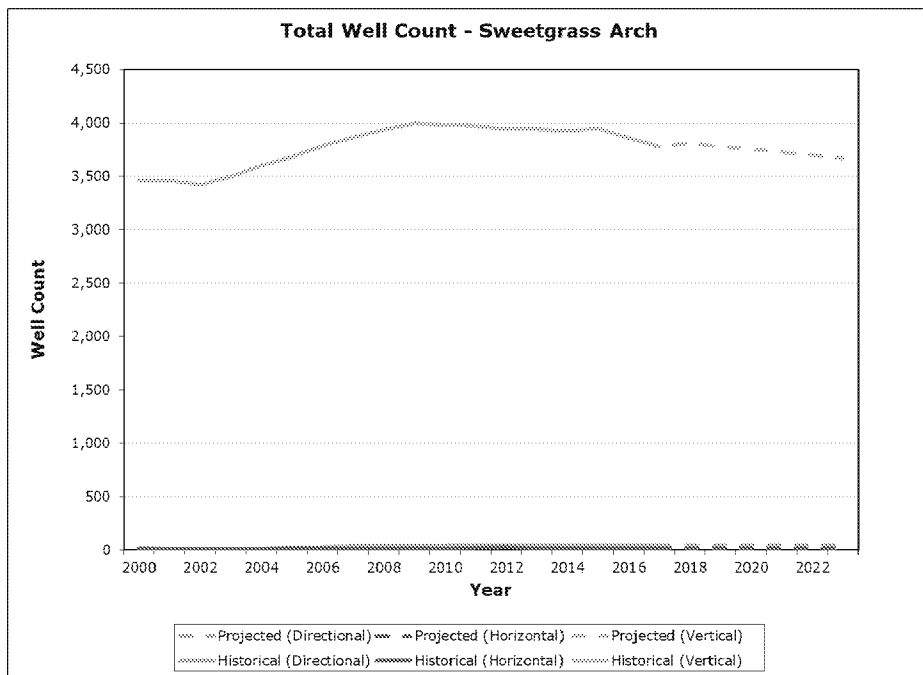


Figure 39. Sweetgrass Basin - Total Well Count

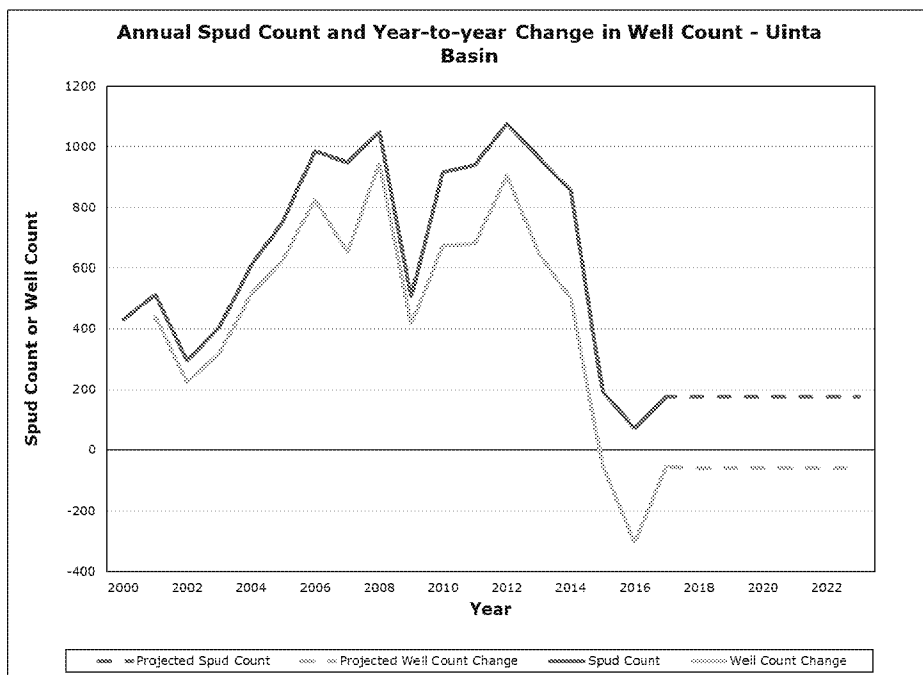


Figure 40. Uinta Basin - Annual Spud Count and Year-Over-Year Change in Well Count

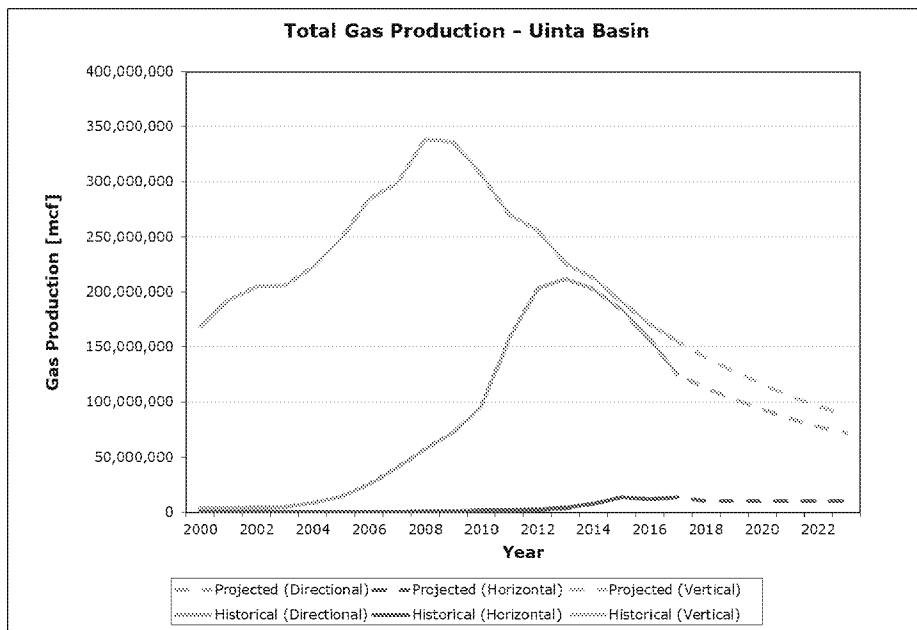


Figure 41. Uinta Basin - Total Gas Production

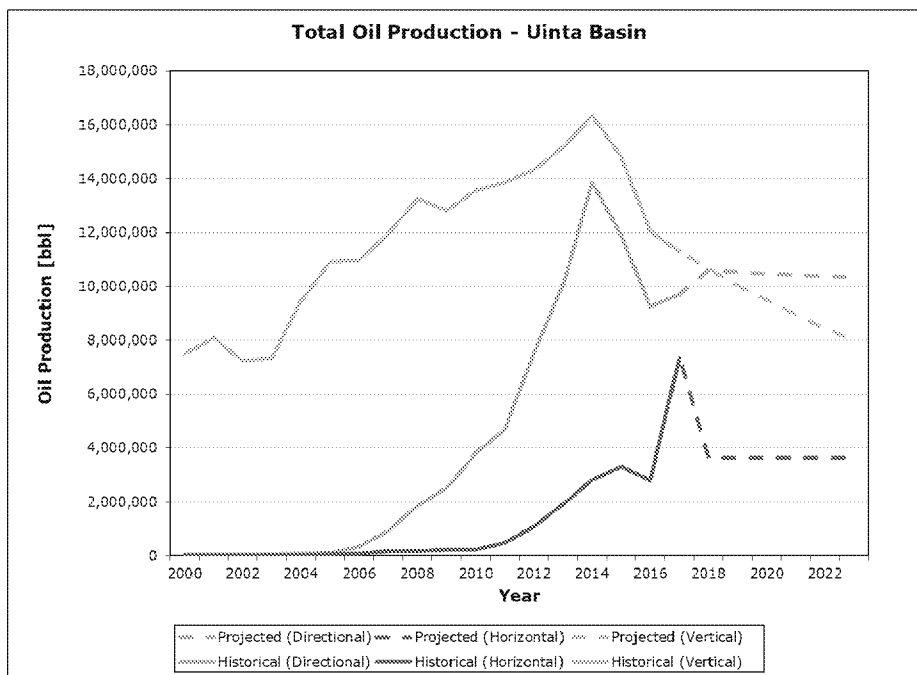


Figure 42. Uinta Basin - Total Oil Production

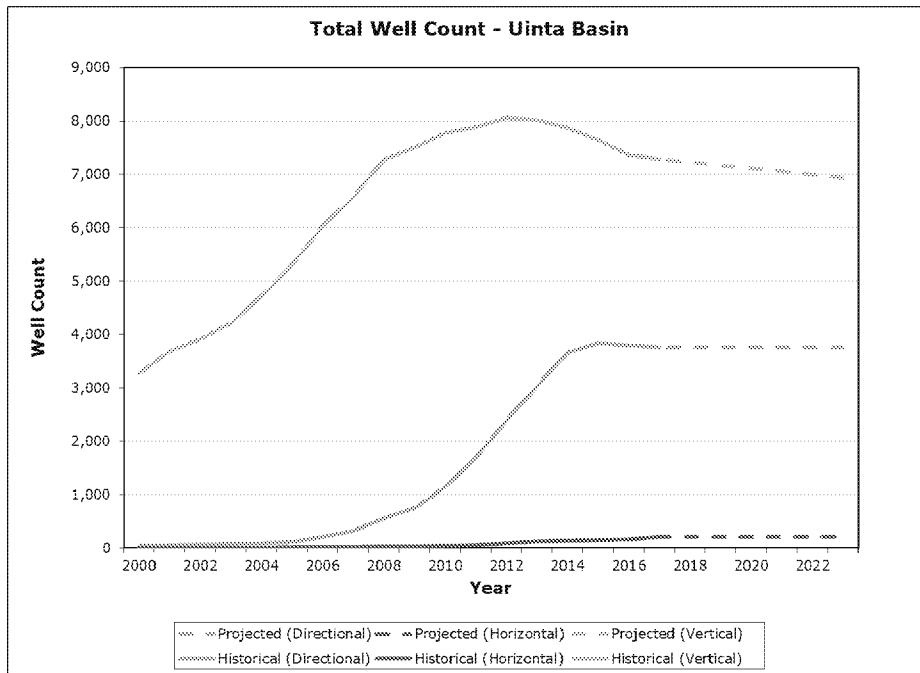


Figure 43. Uinta Basin - Total Well Count

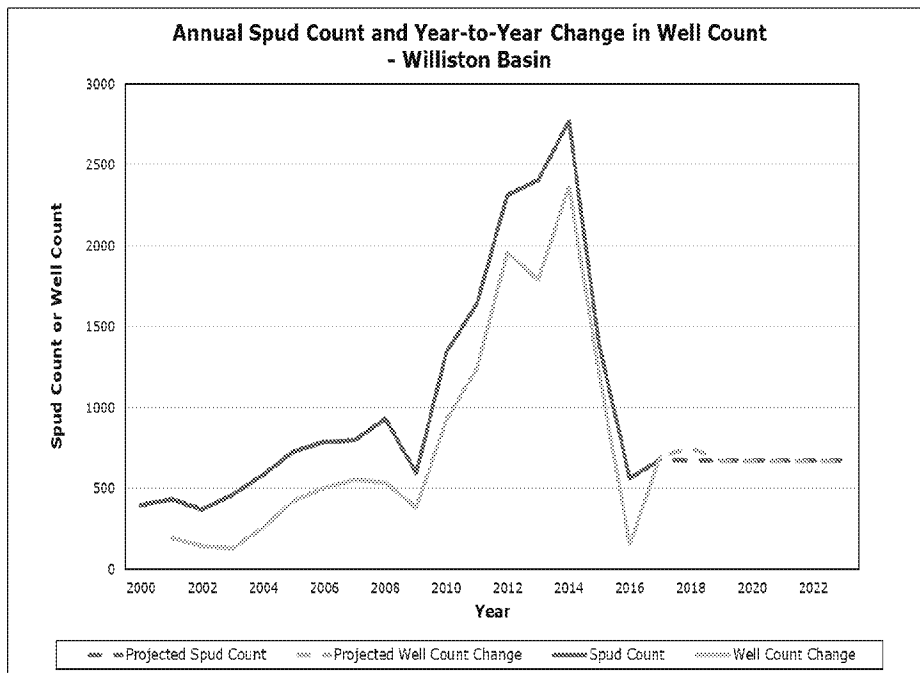


Figure 44. Williston Basin - Annual Spud Count and Year-Over-Year Change in Well Count

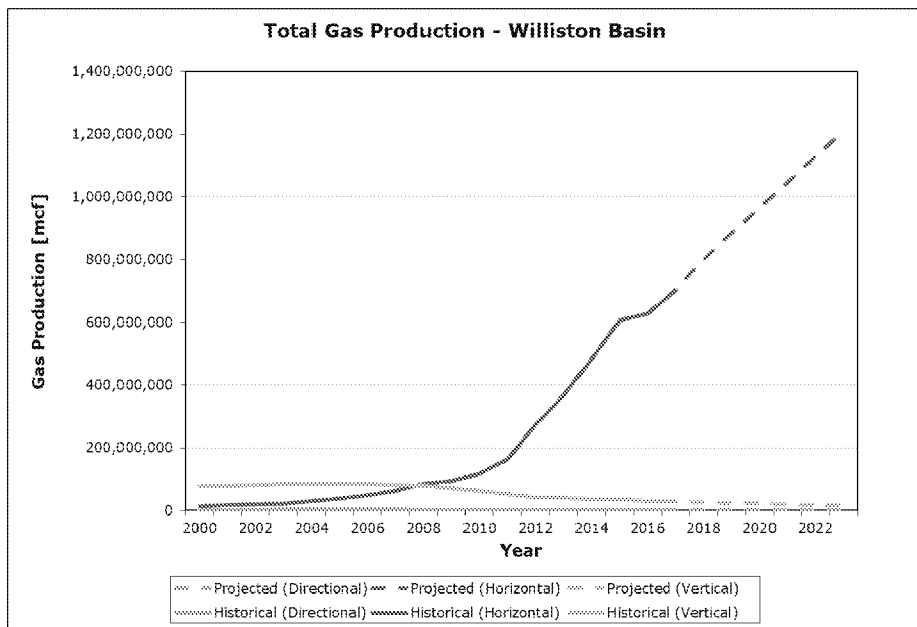


Figure 45. Williston Basin - Total Gas Production

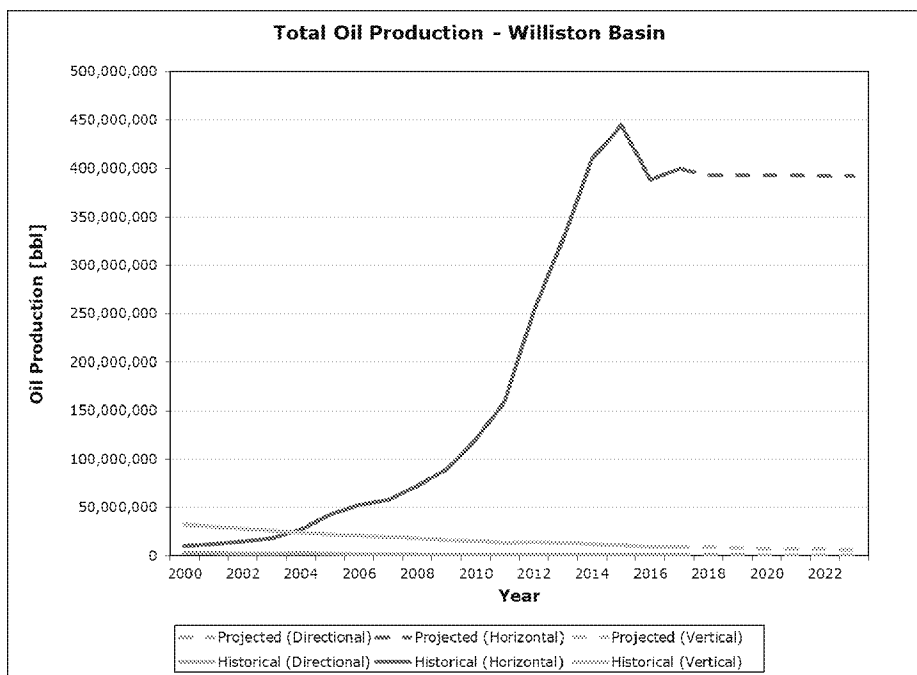


Figure 46. Williston Basin - Total Oil Production

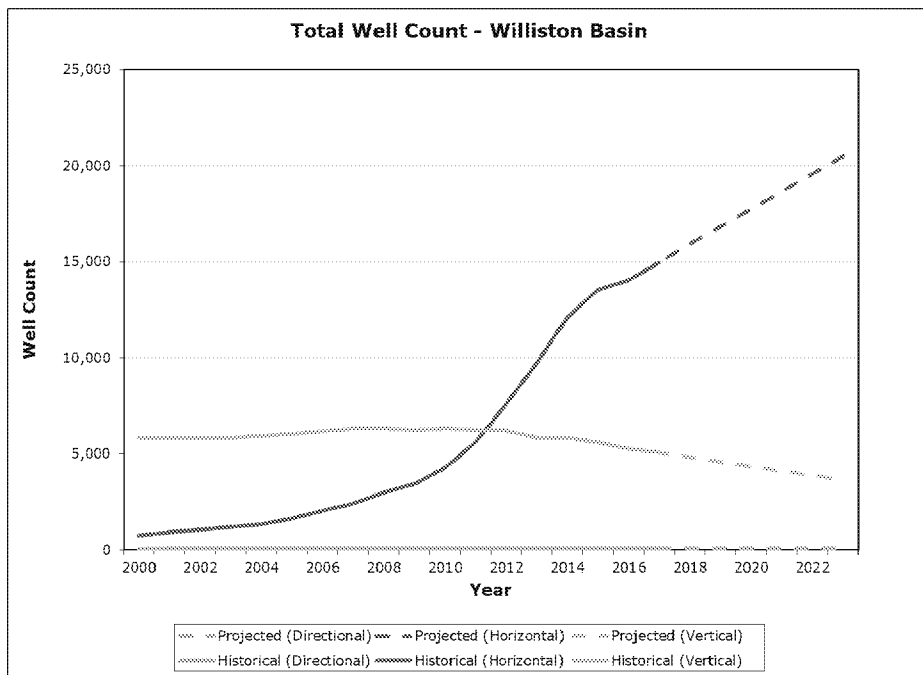


Figure 47. Williston Basin - Total Well Count

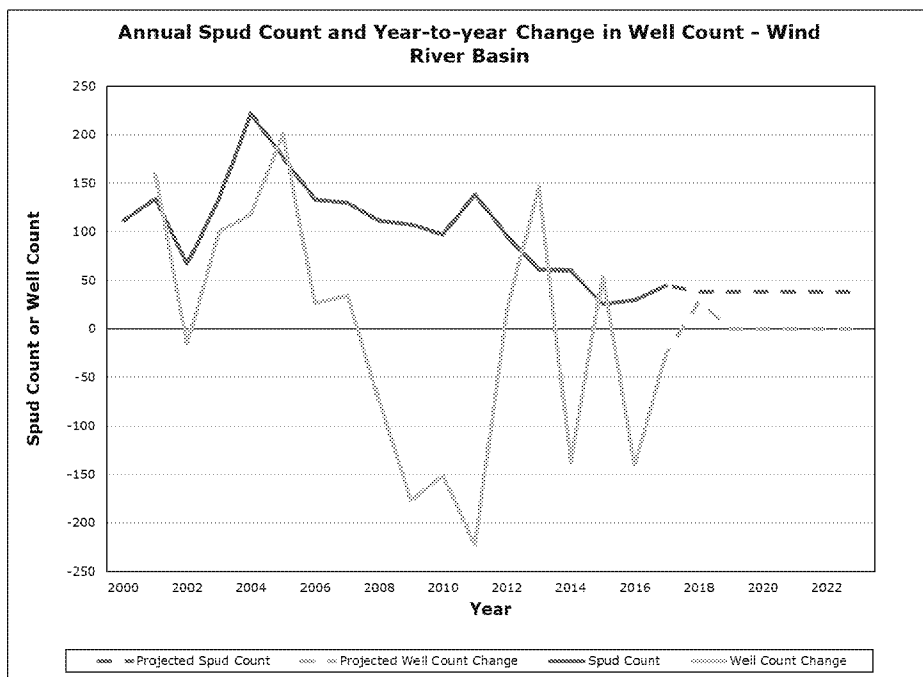


Figure 48. Wind River Basin - Annual Spud Count and Year-Over-Year Change in Well Count

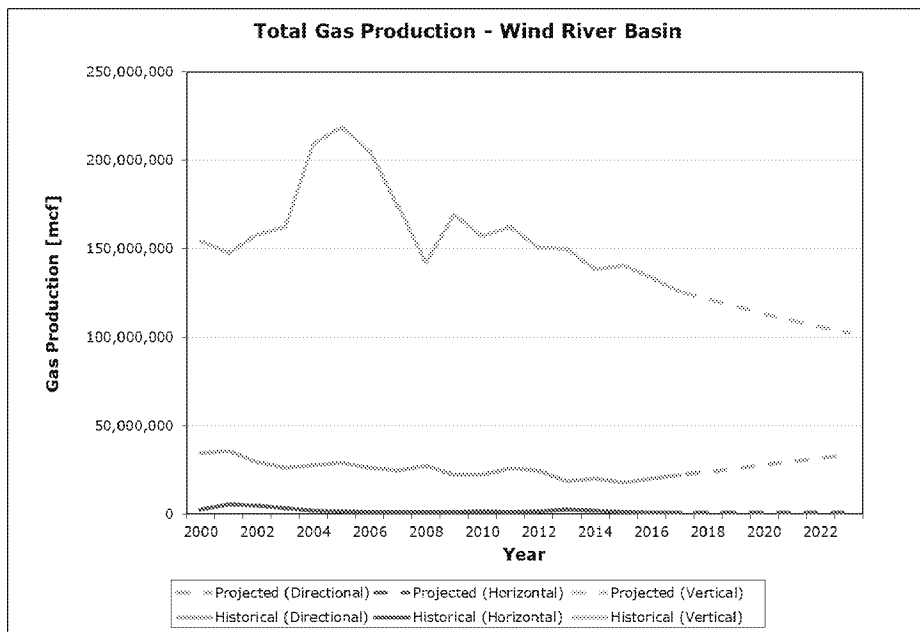


Figure 49. Wind River Basin - Total Gas Production

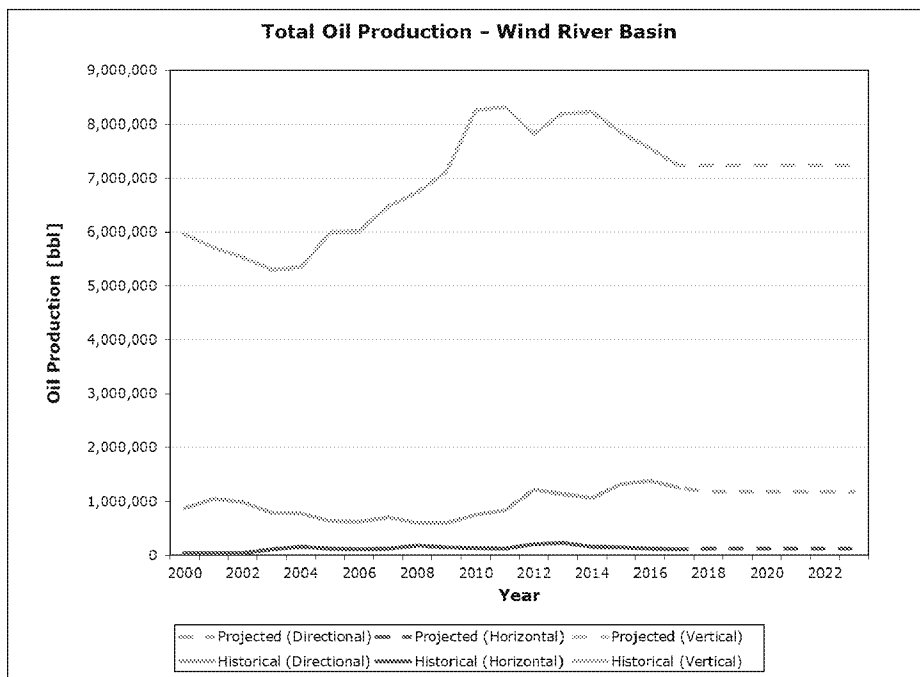


Figure 50. Wind River Basin - Total Oil Production

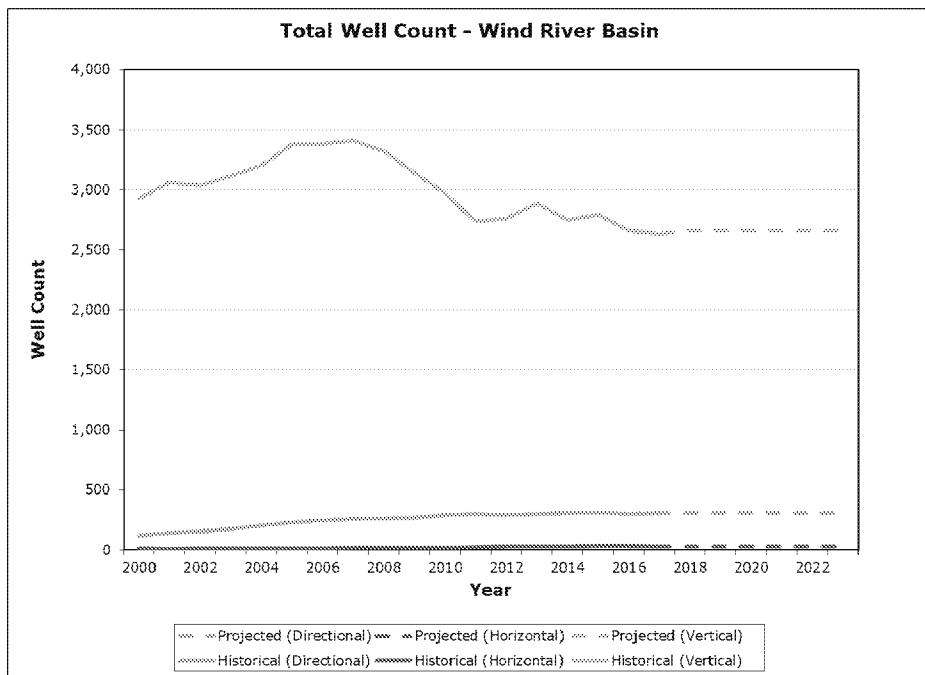


Figure 51. Wind River Basin - Total Well Count